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Scheduling Irrigation for Corn in the Southeast

ABSTRACT

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This publication reports the results of a 3-year project to evaluate the effectiveness of using a computer-based water-balance method to schedule irrigation for corn in the Southeastern Coastal Plain. The method, which requires inputs of crop, soil, soil moisture, and meteorological data, gave good results at the five locations involved in the project.

KEYWORDS: computer-based water balance, corn, crop water requirement, drought, evapotranspiration, humid region, irrigation, irrigation management, irrigation scheduling, maize, plant-available water, plant rooting volume, plant-water stress, precipitation, rainfall, soils, soil-water retention, solar radiation, Southeastern Coastal Plain, Southeastern United States, tensiometers, water, water balance, water management, _Zea mays_ L.

EXECUTIVE SUMMARY

A regional research project conducted at six locations in the Southeastern Coastal Plain during the period 1979-81 evaluated a computer-based water-balance (CBWB) method for scheduling irrigation and compared corn grain yields and water requirements for irrigation as scheduled by the CBWB method and a tensiometer method. The primary region represented by these locations is the humid, thermic Southeastern United States, which is characterized by a mean frost-free growing season of about 250 days and an annual rainfall that normally equals or exceeds annual evapotranspiration (ET). Unfortunately, total rainfall during the growing season often does not satisfy growing season ET, and rainfall during the growing season is often not well distributed. Additionally, the coarse-textured soils of the region have low soil-water retention and allow only a low plant-root volume. The corn crop is thus frequently subjected to drought periods and water stress.

The CBWB procedure used maximum and minimum daily temperatures and daily solar radiation to estimate daily ET according to the Jensen-Haise equation. Each time the CBWB procedure was operated, irrigation requirements and daily ET were estimated from forecast weather values for the next 5 days. Weather forecasts for all locations were provided twice weekly by the National Weather Service Office in Columbia, SC, to Clemson University, where the CBWB procedure was operated for all locations. Irrigation management criteria for the tensiometer method were determined by the cooperating scientists at each location because of soil, climate, and crop factors specific to the location. Individual researchers were also allowed considerable latitude in selecting input parameters to and in interpreting output from the CBWB procedure.

The five cooperating locations were Clayton, NC; Florence, SC; Blackville, SC; Tifton, GA; and Gainesville, FL. Results from each are presented as separate chapters. Results from a sixth location (Suffolk, VA) were also included, although this location was not a formal part of the regional study. These results were included because similarities in experimental objectives, corn hybrid, and overall procedure contribute to this project. Finally, the CBWB and weather forecasting procedures are described in separate chapters. Within the chapter for each location, results regarding the CBWB procedure are presented in a consistent format, particularly in the case of figures showing seasonal soil-water content, rainfall, and irrigation. Individual location reports often include results for other treatment variables, such as tillage or additional irrigation scheduling methods because the regional irrigation scheduling research was combined with other, compatible research desired by the cooperating State experiment stations.

In all cases, corn grain yields were higher for irrigated treatments than for nonirrigated treatments. Although there were differences (typically small) in the volume of irrigation water required by the two irrigation scheduling methods, there were generally no significant differences in corn grain yield between the two methods. Because root-restricting, compacted soil layers are common in Coastal Plain soils, deep tillage (subsoiling or chisel plowing) was the most common additional treatment. With one exception, deep tillage increased corn grain yields, even with irrigation, at sites where layered soils were present.

The CBWB procedure performed very well, considering the wide range of soil and climatic conditions experienced during the 3 years of this study. Performance of the CBWB-scheduling procedure was similar to that of the tensiometer method, with neither indicating clear superiority. Consequently, both methods can be confidently used, the choice depending upon personal preference and specific circumstances. However, the CBWB procedure provides a 5-day forecast for planning purposes, a distinct advantage. Refinement of soil and crop parameter values used in the CBWB procedure, possibly from further analyses of these data, and the incorporation of additional features into this or another CBWB procedure would improve its accuracy. This could result in significant water and energy savings and increased water use efficiency. Improved accuracy will reduce the requirement for recalibration of the CBWB procedure to once or twice each season.

Spatial variability in soil and soil-water conditions significantly affected the gravimetrically determined soil-water contents that were used to initialize and correct the CBWB. These problems are not unique to the CBWB procedure but are common to all soil-based irrigation management techniques. A computer-based method minimizes these problems because it allows the operator to integrate soil and water variability within a field or management unit at system initiation, eliminating the need to consider it at each decision point.

There was considerable, but not unexpected, variation in the performance of the CBWB procedure (as determined by comparing simulated and measured soil-water contents) with site, weather, and soil. In most, but not all, cases the CBWB procedure overestimated the volume of plant-available soil water stored in the profile, particularly during periods of high ET (corn pollination and grain fill). There was no consistent explanation for the deviation between measured and simulated soil-water contents across locations. For most locations, it was hypothesized that differences among soils and soil-water retention values used in the CBWB procedure caused the deviations. Research personnel at most locations experienced much difficulty in selecting or determining values for the upper and lower limits of plant-available soil water that effectively represented each soil layer in the research area.

In accomplishing the objectives of this project, two major contributions were made to irrigation technology for the humid region. First, these results provide a unique evaluation of two irrigation management methods for corn in a wide range of soil and climate conditions and establishes the computer-based water balance procedure as a technique at least equal to the tensiometer method for managing irrigation. Second, the soil, crop, and meteorological data assembled during this study will be extremely helpful in the development and refinement of crop and soil parameters and for the evaluation of future computer-based scheduling procedures and simulation models.

CONTENTS

The data for this publication were collected during 1979-81; however, the information reported is not time-sensitive and will remain unique in its importance and contribution to the irrigation technology for the humid Southeast.

Scheduling Irrigation for Corn in the Southeast

C.R. Camp and R.B. Campbell,
Coordinators

1. INTRODUCTION

C.R. Camp and R.B. Campbell[1]

NEED FOR IRRIGATION

The Southeastern Coastal Plain (fig. 1.) has a humid, subtropical climate and a mean frost-free growing season of about 250 days. Its annual rainfall normally equals or exceeds evapotranspiration (ET) and may be adequate for crop production; however, it is often not well distributed during the crop growing season. Total rainfall during the growing season often does not satisfy ET requirements, and plant water stresses occur. More importantly, drought periods that are of sufficient duration and intensity to cause reductions in crop yield can occur. Sheridan et al. (1979) showed that 22 consecutive days with less than 6 mm of rainfall on any day could be expected every other year. In the Coastal Plain, crops suffer from water stress after 3 to 7 days without rainfall because of the low water-holding capacity of soil and low soil volume explored by plant roots. The combination of soil physical properties and high probability of short-term drought makes it unlikely that high yields can be realized yearly from crops with high water requirements, such as corn.

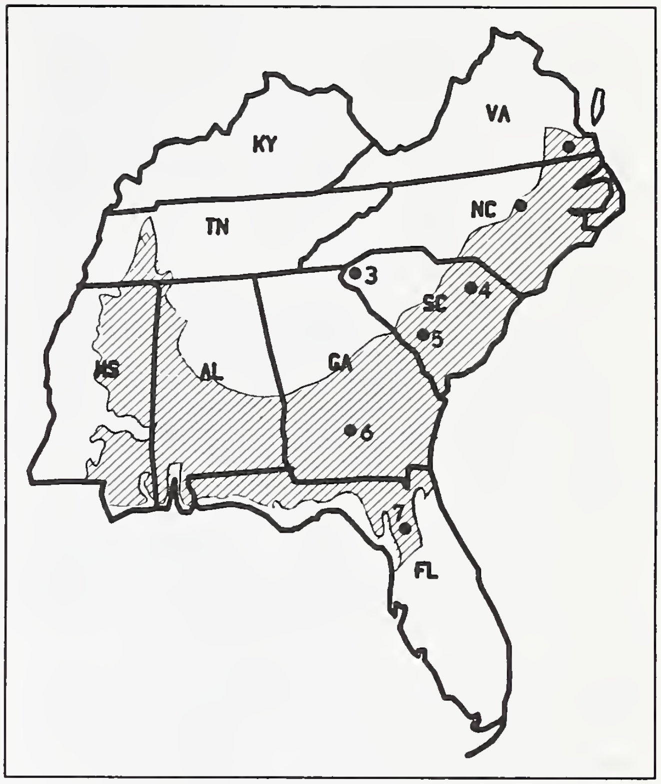

Figure 1.
Field research sites for a regional irrigation scheduling research project in the Southeastern Coastal Plain (shaded area) include 1, Suffolk, VA; 2, Clayton, NC; 4, Florence, SC; 5, Blackville, SC; 6, Tifton, GA; and 7, Gainesville, FL. Computer-based water balance computations for all locations except Suffolk, VA, were performed at 3, Clemson, SC.

In addition to a coarse texture and very low water-holding capacity, many of the soils have compacted layers. This compaction, caused by tillage, traffic, or genetic characteristics, restricts plant rooting to very shallow depths (0.30 m to 0.45 m). Plant nutrients, especially nitrogen, are easily leached through the soil profile of many soils following rainfall or a combination of rainfall and irrigation that exceeds soil storage capacity. Farmers have used deep tillage techniques, such as subsoiling and chisel plowing, to disrupt the compacted soil layers in an attempt to increase rooting depth and uptake of both water and nutrients from the subsoil. Much of the rainfall during the growing season results from afternoon convective thunderstorms, which can be moderate to

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high in intensity. Consequently, much of this rainfall is lost as surface runoff and is not used effectively for plant transpiration. If heavy rainfall follows irrigation or other rainfall, adverse soil aeration problems can arise and last for several hours to a few days (Campbell and Phene 1977).

Corn is important to the region but generally does not rank high as a cash crop because it is utilized primarily as an intermediate product for poultry, hogs, dairy, and beef. When quantities of feed grains produced are compared with feed grains used, it is apparent that most States in this region are grain deficient (Bauer and Burch 1981). Although the growing season is long, most of the corn grain is produced by short-season hybrids planted very early in the spring to minimize the effects of drought, heat, or high insect pressures during the summer. The reproductive growth stage of corn is most critical and is very sensitive to even short periods of moisture stress (Shaw 1977).

The need to irrigate corn in the region is well documented (Van Bavel and Carreker 1957, Van Bavel et al. 1957, Van Bavel and Lillard 1957, Sheridan et al. 1979). Irrigated cropland has increased 40 to 400% for most States of the region during the last decade. A significant portion of this land is devoted to corn production (table 1). Further growth of irrigation in the region is projected for the near future.

Water supplies are generally adequate in the Coastal Plain, but energy costs for pumping water from wells and reservoirs will require careful economic analyses during both the design and management of irrigation systems. Because of the relatively short growing season required for corn in this region, many farmers are producing other crops before or after corn to increase land and equipment utilization and enhance economic return. With the rapid expansion of irrigated corn land and with the soil, climate, and cultural problems associated with crop

Table 1.
Area irrigated and in corn production in the Southeastern United States in 1984 and changes in irrigated area since 1975

State	Irrigated area	Change since 1975	Irrigated corn area	
	ha	%	ha	%
Alabama	65,448	+403	24,300	37
Florida	759,517	-2	31,590	4
Georgia	481,950	+417	131,625	27
Mississippi	190,350	+42	N/A	N/A
North Carolina	82,588	+81	14,580	18
South Carolina	56,962	+260	16,200	28
Virginia	35,438	+100	6,075	17
Tennessee	11,097	+40	3,969	36

Source: Irrigation Journal (1985).

production in the region, there is a critical need for knowledge of crop water requirements and for irrigation management technologies which will efficiently and effectively satisfy those crop water requirements.

IRRIGATION MANAGEMENT METHODS

Several irrigation management methods have been suggested for humid regions, but few have been accepted by irrigation managers in the Southeastern United States. The use of soil-water potential (tensiometers) to manage irrigation is widely recognized and recommended (Bruce et al. 1980, Rhoads 1982), but is not widespread (Lambert 1980). Instrument cost, maintenance requirements, and time and labor requirements are the most common reasons cited for not using tensiometers.

Evaporation from containers such as National Weather Service Class A evaporation pans and other metal containers of various sizes have been used either to physically simulate a soil-water balance or to estimate potential ET in water balance procedures (Westesen and Hansen 1981, Doty et al. 1982). Some researchers have covered these containers with screen to reduce contamination and water loss caused by animals and have found that evaporation is reduced to a value nearly equal to potential ET (Campbell and Phene 1976).

Various adaptations of the water balance technique have been developed but are restricted to specific crops, soils, or climatic regions and require tedious recordkeeping or interpretation of charts and figures (Lambert 1980, Doty et al. 1982, Gregory and Shottman 1982). These methods require knowledge of the soil-water retention characteristics, measured or estimated daily ET, measured rainfall and irrigation amounts, and initial soil-water storage.

Computers have been widely used for several years in arid regions to eliminate tedious recordkeeping associated with water balance methods and to estimate daily ET based upon daily meteorological inputs (Jensen et al. 1970, Kincaid and Heermann 1974). Although efforts have been made to adapt this technology to humid regions and to incorporate rainfall predictions into the decision-making process, the use of computers in scheduling irrigation is neither widely recommended nor practiced by irrigation managers (Rochester and Busch 1972, Lambert 1980). Difficulties in estimating daily ET and in accurately assessing infiltration, runoff, and deep percolation losses from humid-region soils are suggested as reasons these methods are not widely accepted.

Development of water balance methods for programmable calculators (Kincaid and Heermann 1974) and personal computers (Lambert 1980) and the increased availability of these machines provide the opportunity for using a single computer to schedule the irrigation of several locations, which may differ widely in soil, crop, and climate. An additional benefit of computer-based methods is the capability to forecast seasonal water resource needs so that either irrigation equipment may be matched to existing water resources or additional water resources may be developed to satisfy irrigation requirements.

Regardless of the method used in managing irrigation, soil variability and water application variability within the management unit must be recognized and included in the decision-making process. In the case of discrete soil-water-potential measurements (tensiometer), the number and location of instruments in relation to spatial variability of soil physical properties must be considered in the design of the monitoring system as

well as in the interpretation of measurements. Likewise, knowledge of plant available soil water and crop rooting depth for soils in the management unit is critical for successful application of any water balance procedure whether it be based on the use of computers, manual bookkeeping, or an evaporation pan simulator.

In all methods, control sites must be selected within the management unit so that they adequately represent soil and crop conditions for the entire unit. These key control sites will then be used to determine the timing and amount of irrigation water to be applied. With the development of automated irrigation machines and suitable soil-water sensors, it will be possible to vary the irrigation application to satisfy soil needs within a management unit during a given irrigation cycle. Even in this case, some compromise will be required because soil changes will seldom coincide with irrigation machine movement patterns.

REGIONAL COOPERATIVE RESEARCH

Little data are available in the Southeastern United States comparing irrigation scheduling methods, comparing methods for estimating daily ET, or in determining crop water requirements. A critical need exists to evaluate irrigation scheduling methods and to assemble a data base quantifying water use by crops in this region. Consequently, a group of interested researchers organized a regional work group to accomplish some of this research.

Because the research was funded in part by the Agricultural Research Service of the U.S. Department of Agriculture, the Coastal Plains Soil and Water Conservation Research Center acted as coordinator for the project. Participants included the North Carolina Agricultural Research Service at Clayton; the South Carolina Agricultural Experiment Station at Florence, Blackville, and Clemson; the Georgia Agricultural Experiment Station at Tifton; and the University of Florida Institute of Food and Agricultural Sciences at Gainesville. Field research sites were located at Clayton, NC; Florence, SC; Blackville, SC; Tifton, GA; and Gainesville, FL (fig. 1). Research was conducted at all of these locations during 1979, 1980, and 1981.

Objectives of this research were (1) to evaluate a computer-based water balance (CBWB) irrigation scheduling technique for the region, (2) to compare corn growth, yield, and water requirements when irrigation is scheduled by the CBWB method versus the tensiometer method, (3) to assemble crop-water-use data in relation to meteorological data for the region, and (4) to evaluate the CBWB procedure from a user's point of view, particularly with respect to input parameter selection and interpretation of output guidance.

Because this research was only partially funded by ARS, individual researchers often incorporated these research objectives with others specific to their location. In some cases, additional irrigation scheduling methods, additional crops, and tillage variables were included in the experimental design. Individual researchers also selected management criteria for the tensiometer method that were most appropriate for their soils and locations.

The CBWB procedure was developed and operated by J.R. Lambert at Clemson (fig. 1). Weather forecasts were provided to Dr. Lambert for each location twice weekly during the growing season by M.E. Brown, National Weather Service Office in Columbia, SC. Irrigation schedules and data were communicated directly between Dr. Lambert and individual locations.

Similar research was subsequently initiated in 1980 at Suffolk, VA, by personnel of the Virginia Agricultural Experiment Station and ARS under a different program (fig. 1). However, timing and goals of this effort were not such that identical procedures could be used. The specific computer-based scheduling procedure used at the Virginia location was different from that used by the work group but was similar in concept. Their results, including a description of the scheduling procedure used, are included in this report because of many similarities.

Except for two chapters, this report is organized by individual locations where the research was conducted. Scientists responsible for research at each location prepared the respective reports to stand alone and are technically responsible for their content. The detailed descriptions of the CBWB and weather forecasting procedures are two separate chapters. Figures showing the CBWB performance at each location are reported in a standard format to facilitate comparison among locations.

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2. COMPUTER PROGRAM FOR SCHEDULING IRRIGATION BY WATER BUDGET

J.R. Lambert, I. Israel[1], and
I. Meirson[2]

INTRODUCTION

Irrigation scheduling by use of a water budget is analogous to bank deposit scheduling by use of a money budget or running checkbook balance. Daily withdrawals are subtracted from the checkbook balance and any accretions are added as they occur. Should cash flow scheduling project the balance to drop below some minimum, a special deposit is called for. In the field, daily evapotranspiration amounts are withdrawn from storage in the soil profile. Any rainfall is added to the storage or, if the water-holding capacity is exceeded, to deep percolation. Should water budget analyses project the soil water to drop below some minimum level, the need for irrigation is indicated. Weather forecasts allow more accurate prediction of evapotranspiration rates and projections of soil water content (WC) than do average values of evapotranspiration.

This chapter describes the procedure used to calculate a daily water balance for the soil under a growing corn crop. Methods of estimating parameters and algorithms for the procedure are included, as are methods of using weather forecasts to project evapotranspiration and consequent water balance. Filing of observed weather data for use by the irrigation scheduling computer program is also detailed.

PROGRAM ORGANIZATION

The overall strategy of the computer program for irrigation scheduling, including filing of observed weather, is shown in figure 1. Although the program is broken into two segments of code,

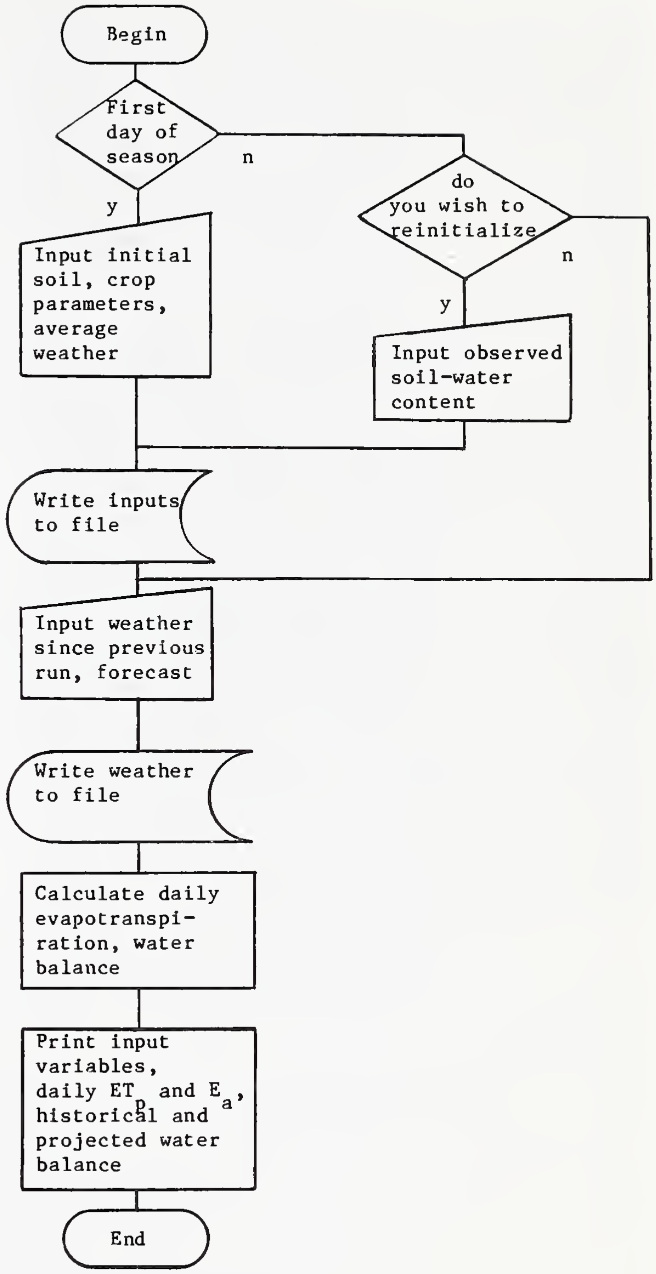

Figure 1.
Flow diagram of computer program for scheduling irrigation by water budget. Program code is divided into two segments: WEATHER, which handles all parameters and variables related to weather, and SCHED, which handles parameters, variables, and algorithms related to daily evapotranspiration and water balance.

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named WEATHER and SCHED, this flow chart describes the functions of the entire package. Technical organization will be detailed later. Supplementary information on the two programs, WEATHER and SCHED, is presented in the appendix under "Program Listings," "Dictionary of Terms," and "Annotations to Program."

Crop parameters (for example, days to maturity and planting date), soil parameters (for example, number of layers and upper limit of available water), and, optionally, historical average weather variables (for example, daily solar radiation and maximum temperature) are entered and filed on a diskette to start the growing season. To begin each run, which may occur daily, semiweekly, or sporadically, the weather observed since the previous run and the forecast for the next 5 days are entered. Observed weather data are filed and used to calculate actual daily evapotranspiration rates. To find the current WC balance, evapotranspiration is subtracted daily from, and any rainfall is added to, the profile WC calculated at the end of the previous run. Forecast weather is used to estimate daily evapotranspiration rates for the next 5 days and to project a water balance through that period. Finally, a report is printed to include all daily input variables, calculated evapotranspiration rates, and the daily water balance. Figure 2 is a sample report of a run on 31 July 1980. Details of the program will be described in later sections.

INPUT DATA

Input data required to operate the total irrigation scheduling program may be broken into five categories: (1) soil and crop parameters; (2) observed soil WC; (3) daily inputs of weather, rooting depth, and allowable depletion; (4) weather forecasts; and (5) historical weather. Each of these will be discussed in detail.

Soil and Crop Parameters

The soil characteristics of the field to be irrigated must be described as those

IRRIGATION SCHEDULING FOR EDISS
07/31/80 11:45:15

BACK RECORDS:

DATE	TMAX	TMIN	RAIN	IRRG	WIND	RAD	PEVP	ETP	AETP	RD	AD(%)	AWC(%)	AWC(IN)	DPL(IN)
07/28	94	68			19	379	.216	.201	.178	42.0	50	72.0	3.64	1.42
07/29	94	68			24	391	.215	.207	.179	42.0	50	68.4	3.46	1.60
07/30	95	68			24	403	.215	.215	.183	42.0	50	64.8	3.28	1.78

FORECAST:

DATE	TMAX	TMIN	RAD	ETP	AETP	RD	AWC(%)	AWC(IN)	DPL(IN)	
07/31	91	67	391	.201	.167	42.0	61.5	3.11	1.95	
08/01	94	68	437	.231	.188	42.0	57.8	2.92	2.14	
08/02	95	70	415	.225	.178	42.0	54.3	2.75	2.31	
08/03	97	73	440	.247	.190	42.0	50.5	2.56	2.50	
08/04	92	72	400	.215	.161	42.0	47.3	2.40	2.66	IRRIGATION NEEDED.

Figure 2.
Typical output from water budget program written for a personal computer and used for irrigation scheduling. Variables are defined in the appendix.

of some average soil profile. The profile is divided into not more than four layers, and each layer is assumed to be homogeneous with respect to WC and water-holding characteristics. The limitation of four layers is arbitrarily imposed by array size. The following information on the layers is required:

1. Depth to bottom surface of each layer (in),

2. Upper limit (UL) of available water for each layer (% by volume), and

3. Lower limit (LL) of available water for each layer (% by volume).

Some of the problems involved in accurately defining in situ UL and LL of available water will be discussed later.

The following information is entered but only for information in reporting:

4. Soil series and texture (dimensionless).

The following information is needed to coordinate evapotranspiration or withdrawal rates with weather and with stage of growth of the crop:

5. Planting date of the crop (month/-day),

6. Date of 50% emergence (month/day), and

7. Days to physiological maturity (days).

The following are entered for reporting information:

8. Crop variety (dimensionless),

9. Row spacing (in), and

10. Plant population (plants/acre).

Observed Soil Water Content

Certain data must be established from which to calculate a water budget. These data are the WC values of all the layers of the profile on a given date, and they may be determined before or after crop emergence. Of course, operation of the program cannot begin until the soil-water profile is initialized.

The calculated soil WC may depart from that actually present in the field because of inaccuracies in model estimates of evapotranspiration, effective rainfall, and deep seepage; field sampling problems caused by spatial variability of soil properties, crop canopy, and root distribution; and nonuniform irrigation-distribution patterns. Therefore, periodic reinitialization is highly recommended to bring into agreement the calculated and observed values. Reinitialization consists of making the layer water contents in the model agree with field observations.

If the data inputs and algorithms were perfect, of course, the need for reinitialization would be eliminated. If measured water contents accurately describe the field situation, discrepancies between model predictions and measured values are probably mostly due to the model assumptions and parameters. Reduction of such discrepancies should be a goal of further research. The WC data required for each sample in a profile are as follows:

11. Date of WC samples,

12. Accumulative depth of the sample (in), and

13. WC (% by volume).

The observed WC of a given sample is assumed to be valid for the vertical distance between the accumulative depth

of the sample and the depth of the previous sample (above). For example, if sample 2 depth and WC are 12 inches and 13% and sample 3 depth and WC are 18 inches and 15%, then the WC of the soil between 12 and 18 inches is assumed to be 15%.

One set of WC samples is necessary to begin the water budget calculations. Correction of any discrepancies in the water balance, termed "reinitialization," should be made every 2 weeks. A set of samples is needed at the end of the growing season, preferably at physiological maturity, to validate the model.

Daily Inputs

Several variables are entered, filed, and used in calculating the water balance for each day between the previous and current runs. These are

14. Daily maximum temperature (^{o}F),

15. Daily minimum temperature (^{o}F),

16. Daily rainfall (in),

17. Daily solar radiation (ly),

18. Daily wind run (mi),

19. Daily class A pan evaporation (in), and

20. Any applied irrigation (in).

The Jensen-Haise (1963) method was used to determine evapotranspiration; and, therefore, wind run or pan evaporation was not absolutely required. Some evapotranspiration models do require wind run, and pan evaporation may be used as a check, if not a basis, for water balance calculations.

If weather observations are not available for a given day(s), average values, preferably for the location, may be determined from the historical weather polynomial file if it has been filled at the beginning of the season. This file is discussed more fully later, under "Historical Weather" and "Historical Polynomial File."

The following is also input on a daily basis and allows for increasing the soil volume from which the roots may withdraw water:

21. Observed rooting depth (in).

Yet another daily input relates to water stored in the delineated root zone:

22. Allowable depletion (%).

It is defined as the portion of plant-available water in the root zone that may be depleted before irrigation is required. This input enables the user to adjust the degree of preirrigation stress as crop growth stage changes, for example.

Weather Forecasts

The daily water balance is projected for 5 days from the date of each run by using the evapotranspiration rate for the current date if the following forecast values are not available on a daily basis:

23. Maximum temperature (^{o}F),

24. Minimum temperature (^{o}F), and

25. Solar radiation (ly).

If the values are available for each of the next 5 days beginning "today," daily water withdrawal is calculated by the Jensen-Haise method.

Historical Weather

The contingency of missing daily maximum temperature (TMAX), minimum temperature

(TMIN), dewpoint temperature (TDEW), pan evaporation (PAN), or solar radiation (RAD) is covered by providing coefficients of a fourth-degree polynomial from which the missing value can be calculated. The method of calculating missing potential evapotranspiration will dictate which of these five variables is critical. The Jensen-Haise method, which requires only TMAX, TMIN, and RAD, was used.

Coefficients for five southeastern locations, calculated using monthly mean values obtained from cooperating researchers and weather atlases, are given in Table 1. A typical equation for generating missing data is

$$T = A_0 + A_1 D + A_2 D^2 + A_3 D^3 + A_4 D^4 \quad [1]$$

where D is the day of the year in question. If solar radiation (RAD) is missing for day 175 at Florence, SC, for example, it would be calculated by the equation

$$\begin{aligned}RAD = 207.264 &+ 1.57239(175) \\ &+ 0.0275796(175)^2 - \\ &1.91975(10^{-4}(175)^3 + 2.87059 \\ &(10^{-7})(175)^4\end{aligned}$$

ALGORITHMS

Several algorithms have been included in the water budget program to describe the processes related to water addition and subtraction.

Soil Profile Description

The soil profile consists of not more than four layers (fig. 3), each of which is assumed to be homogeneous with respect to WC and water-holding characteristics. Division is therefore usually along natural strata boundaries. Experience has indicated that no layer should be unduly thick in relation to the total profile thickness. If it is, erroneously low crop water stress can be implied when the rooting depth extends into a small fraction of the thick layer, which is assumed to be homogeneous with respect to WC. Actual evapotranspiration rate, as described below, would therefore be erroneous. A rule of thumb is to make no layer thicker than 1 foot.

The rooting depth is dynamic; it is a daily input. Water is withdrawn from the layers fully or partially occupied by roots. In addition, water is assumed to be withdrawn from the 4-inch zone immediately below the observed rooting depth in an attempt to describe upward capillary movement of water.

Evapotranspiration

In an attempt to correct for altitude and long-term humidity, potential evapotranspiration is calculated by the modified Jensen-Haise method (Jensen et al. 1970) using the equation

$$E_{tp} = (0.0122\ T - 0.20)\ Rs \quad [2]$$

where

E_{tp} is potential evapotranspiration in in/day,

T is daily mean air temperature, in ^{o}F, and

R_s is solar radiation, in in/day.

Figure 4 compares equation 2 with the original equation by Jensen and Haise (1963):

$$E_{tp} = (0.014T - 0.37)\ R_s \quad [3]$$

Actual evapotranspiration is calculated by the approach

$$E_a = E_{tp}\ K \quad [4]$$

Table 1.
Coefficients (A terms) for calculating average TMAX, TMIN, TDEW, PAN, and RAD for 5 Southeastern U.S. locations

	A0	A1	A2	A3	A4
			Blackville, SC		
TMAX	60.0368	$-1.30875(10^{-1})$	$4.84151(10^{-3})$	$-2.23851(10^{-5})$	$2.75113(10^{-8})$
TMIN	39.8255	$-3.01194(10^{-1})$	$6.69084(10^{-3})$	$-2.94528(10^{-5})$	$3.63484(10^{-8})$
TDEW	39.8594	-0.323766	$6.99164(10^{-3})$	$-3.07752(10^{-5})$	$3.81824(10^{-8})$
PAN	0.076979	$-5.4073(10^{-4})$	$2.66326(10^{-5})$	$-1.41448(10^{-7})$	$1.99528(10^{-10})$
RAD	166.610	1.67867	0.0305788	$-2.11033(10^{-4})$	$3.18994(10^{-7})$
			Florence, SC		
TMAX	58.5923	-0.16434	$5.27965(10^{-3})$	$-2.39539(10^{-5})$	$2.90608(10^{-8})$
TMIN	39.9963	-0.400329	$7.90589(10^{-3})$	$-3.43728(10^{-5})$	$4.26705(10^{-8})$
TDEW	41.6528	-0.433742	$7.86094(10^{-3})$	$-3.26589(10^{-5})$	$3.87946(10^{-8})$
PAN	0.0769797	$-5.4073(10^{-4})$	$2.66326(10^{-5})$	$-1.41448(10^{-7})$	$1.99525(10^{-10})$
RAD	207.264	1.57239	0.0275796	$-1.91975(10^{-4})$	$2.87059(10^{-7})$
			Gainesville, FL		
TMAX	70.831	-0.110516	$3.68938(10^{-3})$	$-1.73391(10^{-5})$	$2.18608(10^{-8})$
TMIN	49.0162	-0.218462	$4.77028(10^{-3})$	$-2.02313(10^{-5})$	$2.39089(10^{-8})$
TDEW	49.3709	-0.274856	$5.34318(10^{-3})$	$-2.21561(10^{-5})$	$2.59449(10^{-8})$
PAN	0.0769797	$-5.4073(10^{-4})$	$2.66326(10^{-5})$	$-1.41448(10^{-7})$	$1.99525(10^{-10})$
RAD	214.284	3.37621	$-2.42892(10^{-4})$	$-7.19081(10^{-5})$	$1.31094(10^{-7})$
			Raleigh, NC		
TMAX	54.3175	-0.171042	$5.37096(10^{-3})$	$-2.41537(10^{-5})$	$2.91651(10^{-8})$
TMIN	37.6211	-0.449201	$8.53778(10^{-3})$	$-3.68327(10^{-5})$	$4.56357(10^{-8})$
TDEW	36.9957	-0.489159	$8.90764(10^{-3})$	$-3.77152(10^{-5})$	$4.60278(10^{-8})$
PAN	0.0769737	$-5.4073(10^{-4})$	$2.66326(10^{-5})$	$-1.41448(10^{-7})$	$1.99525(10^{-10})$
RAD	196.045	0.962745	0.0339533	$-2.15454(10^{-4})$	$3.16332(10^{-7})$
			Tifton, GA		
TMAX	65.1143	-0.209331	$5.40295(10^{-3})$	$-2.42609(10^{-5})$	$2.99798(10^{-8})$
TMIN	45.5585	-0.349384	$6.75139(10^{-3})$	$-2.90305(10^{-5})$	$3.56524(10^{-8})$
TDEW	41.2301	-0.36671	$7.2474(10^{-3})$	$-3.12637(10^{-5})$	$3.8432(10^{-8})$
PAN	0.076979	$-5.4073(10^{-4})$	$2.66326(10^{-5})$	$-1.41448(10^{-7})$	$1.99525(10^{-10})$
RAD	222.084	1.12256	0.0311967	$-2.00506(10^{-4})$	$2.92088(10^{-7})$

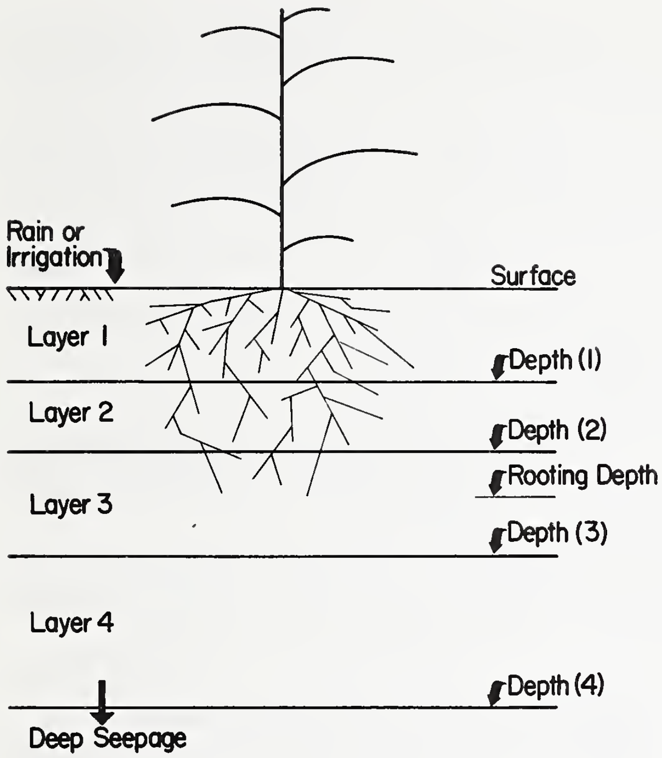

Figure 3.
Root zone of irrigated crop as conceptualized in water budget program.

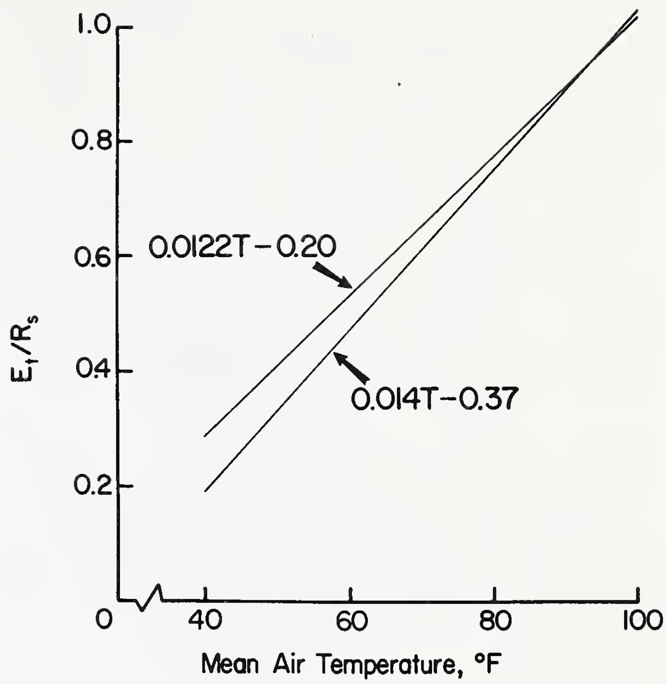

Figure 4.
Comparison of equations 2 and 3 for calculating potential evapotranspiration (E_t) as a function of solar radiation (R_s) and temperature (T).

where

K is based on K_c, K_θ, and the time after significant rainfall (equation 9),

K_c is a coefficient for crop canopy cover or stage of growth, dimensionless, and

K_θ is a coefficient related to available soil water, dimensionless.

This approach is similar to that proposed by van Wijk and de Vries (1954).

The crop coefficient for corn, K_c, is calculated from a regression fit to data published by Jensen (1973).

$$K_c = 0.17 - 0.4276t_b + 2.756t_b^2 - 1.583t_b^3 \qquad [5]$$

if $t_f < 0.69$ and $t_b = t_f/0.69$,

$t_f = (t - t_p)/L$

$$K_c = 0.915 + 0.01195t_a - 0.0004688t_a^2 + 2.75(10^{-6})t_a^3 \qquad [6]$$

if $t_f \geq = 0.69$, then

$t_a = t - t_p - 0.69\ L$

where

t_b = t_f normalized to the period between planting and development of effective canopy cover or 0.69 L, dimensionless,

t_f = fraction of growing season, planting to maturity, dimensionless,

t = current day of year,

t_p = date of planting, day of year,

L = days from emergence to physiological maturity,

t_a = time after development of effective canopy cover, days.

The relationship between the crop coefficient and time or stage of growth is divided into two segments at the point of effective canopy cover development. This point is estimated to occur at 0.69 of the length of the growing season (fig. 5).

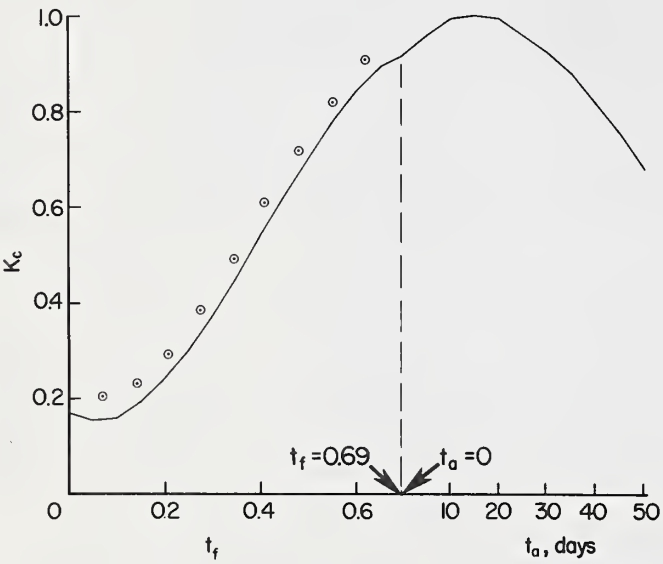

Figure 5.
Crop coefficient (K_c) for corn as related to fraction of growing season (t_f) and time after development of effective canopy cover (t_a).

The soil-water coefficient, K_θ, is calculated by the equations of Jensen et al. (1971).

$$K_\theta = \log(1 + 100\ \theta/\theta_c)/\log(101) \quad \text{if } \theta/\theta_c > 0.4 \qquad [7]$$

$$K_\theta = 2\ \theta/\theta_c \quad \text{if } \theta/\theta_c < 0.4 \qquad [8]$$

where

θ = WC, in the total root zone plus 4 inches, above the LL of available water, cm^3

θ_c = maximum WC (UL), above the LL of available water, cm^3.

Figure 6 shows the relationship of K_θ to θ/θ_c.

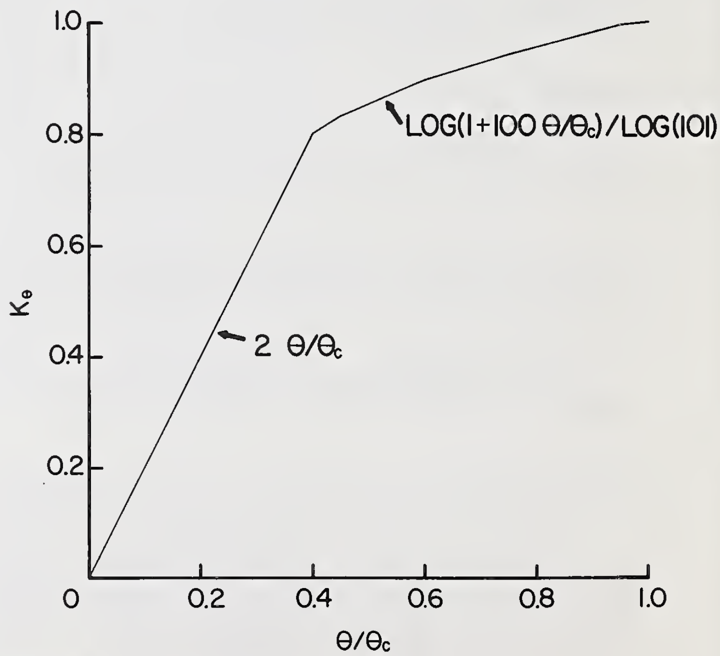

Figure 6.
Soil-water coefficient (K_θ) as related to the fraction of the water content that is maximally available (θ/θ_c).

Rainfall or irrigation wets the soil surface and increases the actual evapotranspiration rate over that estimated by use of K_c and K_θ. To account for this increase, K is modified as follows, according to the number of days after rain or irrigation exceeding 0.25 inches (Jensen et al. 1971):

Day 1, $K = K_c K_\theta + 0.8\ (0.9 - K_c K_\theta)$

Day 2, $K = K_c K_\theta + 0.5\ (0.9 - K_c K_\theta)$

Day 3, $K = K_c K_\theta + 0.3\ (0.9 - K_c K_\theta)$

Day 3, $K = K_c K_\theta$. [9]

Figure 7 illustrates the relationship between K and $K_c K_\theta$.

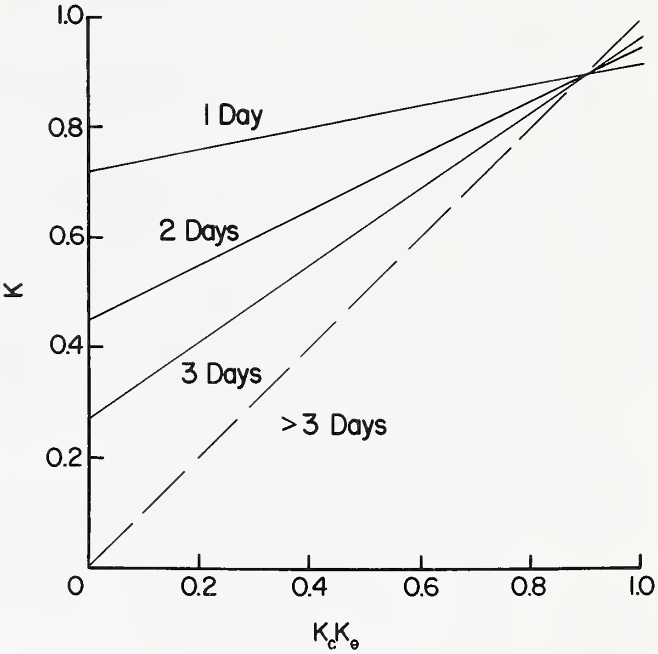

Figure 7.
Relation between K and $K_c K_\theta$ as affected by the number of days after rainfall or irrigation exceeding 0.25 inches.

Water Balance

Actual evapotranspiration calculated by equation 4 is removed from the root zone by soil layers. If the available water in the first or upper layer exceeds the actual evapotranspiration for the day, E_a is subtracted from the WC of the first layer. Otherwise, any available water is subtracted from the first layer and the excess E_a is subtracted from the second layer and deeper layers, as necessary.

Rainfall or irrigation is added to the upper soil layer. If the new value of WC exceeds the UL, the excess is removed and added to the second layer. The remaining layers are treated likewise. Any excess from the fourth layer is lost to deep seepage.

Time steps of one day are taken by the model. Each day is assumed to begin and end at time of weather observation. Evapotranspiration for the day is subtracted first. Then, any rainfall or irrigation is added.

OPERATION

The water budget program was originally written for the Radio Shack TRS-80 model I computer by Itzhak Meirson. Israel Israeli modified the program to run on the model III. The modified program also runs on the model 4. Two disk drives are preferable -- one for the program and one for the data. As indicated in figure 1, the water budget program has been divided into two segments. WEATHER is used during startup at the beginning of the season to input weather parameters which are required only once and to write those parameters to diskette files. WEATHER is also run during each session during the season to update the current weather file.

```
READY
>RUN "WEATHER"
INITIALIZING
ENTER LOCATION WEATHER UPDATE TO BE DONE FOR - ? examfld1
WEATHER REPORT FOR EXAMFLD1
05/04/83 08:01:07
NO HISTORIC WEATHER INFORMATION FOR EXAMFLD1.
YOU CAN USE EDISTO HISTORIC WEATHER OR INITIALIZE FOR EXAMFLD1.
ENTER 'YES' TO INITIALIZE 'NO' FOR EDISTO - ? yes
ENTER POLYNOM COEFFICIENTS FOR TMAX (SEPARATED BY COMMAS):
          A0 ,      A1  ,      A2     ,      A3    ,       A4
TMAX?  70.831, -0.110516, 3.68938E-3, -1.73391E-5, 2.18608E-8
TMIN?  49.0162, -0.218462, 4.77028E-3, -2.02313E-5, 2.3908E-8
TDEW?  49.3709, -0.274856, 5.34318E-3, -2.21561E-5, 2.59449E-8
PAN?   0.0769797, -5.4073E-4, 2.66326E-5, -1.41448E-7, 1.99525E-10
RAD?   214.284, 3.37621, -2.42892E-4, -7.19081E-5, 1.31094E-7

ENTER STARTING DATE FOR WEATHER FILES (M/O) -? 5/1
ENTER YEAR OF STARTING WEATHER FILE (YY) -? 83
ENTER BLANKS WHERE DATA NOT AVAILABLE, # TO END UPDATING, ANYTIME
ENTER * TO RETYPE VALUE OR & TO END LINE INPUT
DATE     TMAX TMIN  RAIN  IRRIG  WIND  RAD  PEVP   ETP
05/01     89   66   .25           25   456  .23
CHECKING ERRORS
05/02     92   68                 36   525  .26
CHECKING ERRORS
05/03     85   65                 30   415  .19
CHECKING ERRORS
IF YOU STILL WANT TO MAKE CHANGES ENTER 'YES' OTHERWISE 'NO'
CALCULATING EPT
0.228
0.274
0.212
WHEN READY HIT ANY KEY.
REMEMBER THAT THE FILES ARE NOW UPDATED TO 05/03/83.
PROGRAM ENDED NORMALLY
```

Figure 8.
Screen interaction for initial WEATHER run.

SCHED (for scheduling) is used during startup to input soil and crop parameters and initial soil WC variables and to write those parameters and variables to files for later use. At each session during the season, SCHED uses the files generated by WEATHER and SCHED to calculate the daily evapotranspiration and water balance, to file the results on diskettes, and to print the results on paper.

Startup

To use the water budget program for scheduling irrigation, more data and time are required during the initial session at the computer than are required subsequently. Startup procedures described assume a working familiarity with a TRS-80/III or TRS-80/4 computer and the operating system TRSDOS.

WEATHER. The WEATHER program initializes and updates the weather file. Figure 8 is a sample session with the WEATHER program on 4 May 1983 for weather data beginning 1 May. Figure 9, which may follow immediately, is a sample session of the initial SCHEDuling program.

```
RUN "SCHED"
INITIALIZING
ENTER LOCATION SCHEDULING TO BE DONE FOR -? examfldl
SCHEDULING FOR EXAMFLD1
05/04/83 08:10:23
ENTER EXPERIMENT YEAR (YY) - 83
ENTER INVESTIGATOR'S NAME -? henry
ENTER PLANTING DATE (M/D) -? 4/26
ENTER VARIETY NAME - pioneer 3579A
HOW MANY DAYS TO MATURITY -? 120
ENTER SOIL TYPE - aredondo
ENTER NUMBER OF SOIL LAYERS -? 3
LAYER 1 MAX, DEPTH (IN), FC (%), WP (%) -? 12, 14, 6
LAYER 2 MAX, DEPTH (IN), FC (%), WP (%) -? 22, 16, 8
LAYER 3 MAX, DEPTH (IN), FC (%), WP (%) -? 36, 19, 10
ENTER ROW SPACING (IN) -? 36
PLANT POPULATION -? 26500
ENTER YEAR WATER CONTENT SAMPLES WERE TAKEN -? 83
ENTER DATE WATER CONTENT SAMPLES WERE TAKEN (M/D) -? 5/2
WATER CONTENT PROFILE (ENTER '0' FOR DEPTH IF NO MORE)
SAMPLE NO. 1 DEPTH (IN) -? 8
W.C. (%) -? 9
SAMPLE NO. 2 DEPTH (IN) -? 12
W.C. (%) -? 7.5
SAMPLE NO. 3 DEPTH (IN) -? 18
W.C. (%) -? 6.2
SAMPLE NO. 4 DEPTH (IN) -? 26
W.C. (%) -? 14
SAMPLE NO. 5 DEPTH (IN) -? 0

ROOT ZONE DEPTH ON 5/2 -? 14
ALLOWABLE DEPL. (%) -? 60
ROOT ZONE DEPTH ON 5/3 -? 16
ALLOWABLE DEPL. (%) -? 60
FORECAST FROM WEATHER SERVICE:  (If NO FORECAST ENTER - 1)
TMAX, TMIN, RAD - FOR 05/04 -? 85, 65, 550
TMAX, TMIN, RAD - FOR 05/05 -? 88, 68, 600
TMAX, TMIN, RAD - FOR 05/06 -? 78, 65, 500
TMAX, TMIN, RAD - FOR 05/07 -? 75, 63, 400
TMAX, TMIN, RAD - FOR 05/08 -? 80, 65, 450
PROGRAM ENDED NORMALLY
```

Figure 9.
Screen interaction for initial SCHEDuling run.

The weather file for a particular field is identified by the first five characters of the field name. The field named EXAMFLD1 will have an associated weather file named EXAMF/ETP. Therefore, several fields can share a common weather file. Note, however, that both rainfall and irrigation will then be common to all fields.

During the first run of the season, the user has the option of setting up regression coefficients to calculate TMAX, TMIN, TDEW, PAN, and RAD from the day of the year in case of missing data or of using default coefficients for the Edisto Experiment Station near Blackville, as indicated in figure 8. Starting date for the weather file is then entered during

the initial run. A table of observed weather according to the date generated by the program is then completed, beginning on starting date and ending yesterday. Several chances to make corrections are given. Daily potential evapotranspiration (ETP) is then calculated and stored in the weather file.

SCHED. During the initial SCHEDuling run, several data are entered for storage as information. Soil layer depths, UL, and LL are recorded for each layer. Observed WC and depth of sample allow calculation of the actual WC profile at date of initialization. Updating of calculated WC then begins with date of soil water initialization, using either historical average weather or observed weather. Observed root zone depth and desired allowable depletion are required for each historical date.

Beginning with today, forecasts of TMAX, TMIN, and RAD may be input for predicting evapotranspiration during the next 5 days. If forecasts are not available, ETP rate for yesterday will be used for today and the next 4 days. Figure 10 is the computer printout associated with the runs of figures 8 and 9.

Day-to-Day Operation. Typically, during this study, the program was run twice weekly, usually on Monday and Thursday mornings, although the program can be run every 1 to 10 (arbitrary) days. If there is a need to update the weather file for more than 10 days, WEATHER may be run twice. Figure 11 is a screen interaction for both WEATHER and SCHED on 7 May 1983 for field EXAMFLD1. Note that the required data are much fewer than for the initial run. Data on WC samples may be entered, if desired, and should be taken every 2 to 4 weeks to verify that the model is performing satisfactorily. Weather data and forecasts are most of the day-to-day data requirements. The printout of the day-to-day operation is very similar to figure 10.

WEATHER REPORT FOR EXAMFLD1
05/04/83 00:03:04

DATE	TMAX	TMIN	RAIN	IRRG	WIND	RAD	PEVP	ETP
05/01	89	66	.25		25	456	.23	.228
05/02	92	68			36	525	.26	.274
05/03	85	65			30	415	.19	.199

CLIMATE FILE IS NOW UPDATED TO 05/03/83.

IRRIGATION SCHEDULING FOR EXAMFLD1
05/04/83 00:17:37

BACK RECORDS:

DATE	TMAX	TMIN	RAIN	IRRG	WIND	RAD	PEVP	ETP	KS	KC	AETP	RD	AD(%)	AWC(%)	AWC(IN)	DPL(IN)	EW(IN)	
05/02	92	68			36	525	.26	.274	0.53	0.14	.132	14.0	60	17.2	0.25	1.19	0.00	IRRIG NEEDED.
05/03	85	65			30	415	.19	.199	0.34	0.14	.059	16.0	60	13.4	0.21	1.39	0.00	IRRIG NEEDED.

FORECAST:

DATE	TMAX	TMIN	RAD	ETP	KS	KC	AETP	RD	AWC(%)	AWC(IN)	DPL(IN)	
05/04	85	65	550	.264	0.27	0.14	.009	16.0	12.9	0.21	1.39	IRRIGATION NEEDED.
05/05	88	68	600	.303	0.26	0.15	.010	16.0	12.3	0.20	1.40	IRRIGATION NEEDED.
05/06	78	65	500	.226	0.25	0.16	.007	16.0	11.8	0.19	1.41	IRRIGATION NEEDED.
05/07	75	63	400	.172	0.24	0.16	.005	16.0	11.5	0.18	1.42	IRRIGATION NEEDED.
05/08	80	65	450	.207	0.23	0.16	.007	16.0	11.1	0.18	1.42	IRRIGATION NEEDED.

Figure 10.
Printout for initial WEATHER and SCHEDuling runs of figures 8 and 9.

```
READY
 >RUN "WEATHER
ENTER LOCATION WEATHER UPDATE TO BE DONE FOR - ? EXAMFLD1
WEATHER REPORT FOR EXAMFLD1
05/07/83 00:04:09
ENTER BLANKS WHERE DATA NOT AVAILABLE, # TO END UPDATING, ANYTIME
ENTER * TO RETYPE VALUE OR & TO END LINE INPUT
DATE  TMAX  TMIN  RAIN  IRRG  WIND  RAD  PEVP  ETP
05/04  89    65           .85   30   550   .28  .273
CHECKING ERRORS
05/05  63                       45   650   .31  .315
CHECKING ERRORS
05/06  85    61    .35          21   480   .22  .223
CHECKING ERRORS
IF YOU STILL WANT TO MAKE CHANGES ENTER 'YES' OTHERWISE 'NO'
CALCULATING ETP
0.273
0.315
0.223
WHEN READY HIT ANY KEY
REMEMBER THAT THE FILES ARE NOW UPDATED TO 05/06/83.
PROGRAM ENDED NORMALLY
RUN"SCHED"

INITIALIZING
ENTER LOCATION SCHEDULING TO BE DONE FOR - ? EXAMFLD1
SCHEDULING FOR EXAMFLD1
05/07/83 00:07:52
WOULD YOU LIKE TO REINITIALIZE WATER CONTENT WITH NEW SAMPLES?
ENTER 'YES' OR 'NO' -? NO
ROOT ZONE DEPTH ON 05/04 -? 16
ALLOWABLE DEPL. (%) -? 60
ROOT ZONE DEPTH ON 05/05 -? 18
ALLOWABLE DEPL. (%) -? 60
ROOT ZONE DEPTH ON 05/06 -? 18
ALLOWABLE DEPL. (%) -? 60
FORECAST FROM WEATHER SERVICE:       (IF NO FORECAST ENTER -1)
TMAX, TMIN, RAD. - FOR 05/07 -? 88, 63, 520
TMAX, TMIN, RAD. - FOR 05/08 -? 86, 59, 450
TMAX, TMIN, RAD. - FOR 05/09 -? 84, 60, 400
TMAX, TMIN, RAD. - FOR 05/10 -? 90, 66, 665
TMAX, TMIN, RAD. - FOR 05/11 -? 88, 65, 580
PROGRAM ENDED NORMALLY
RUN"WEATHER"
```

Figure 11.
Screen interaction for both WEATHER and SCHED on 7 May 1983 for field EXAMFLD1.

File Structures

The programs use and maintain a set of files consisting of weather and site data. The weather and site files are also updated for changing conditions. Files used by the program are (1) historical polynomial file, (2) weather file, and (3) site parameters.

Historical Polynomial File. This file contains the regression coefficients for calculating the historical weather information for the site. There are five sets of coefficients -- for TMAX, TMIN, TDEW, PAN, and RAD, in the specified order. The regression coefficients are for a fourth degree polynomial (equation 1) and consist of five values for each

variable. We have calculated the regression coefficients using SAS, a statistical analysis program, and, as data, monthly mean values obtained from cooperating researchers and/or historical weather atlases.

The file consists of five records of 255 bytes each. The file is accessed using random access and is formatted as follows:

Record No.	Contents
1	TMAX
2	TMIN
3	TDEW
4	PAN
5	RAD

The record for each location consists of 25 bytes, thus allowing information for a maximum of 10 locations. The format of every record is shown in table 2. After the file is opened for random access, the first record is scanned for the location to be scheduled. After the location is in the file, records 1, 2, and 5 will be processed. (TDEW and PAN are not used to calculate evapotranspiration by the Jensen-Haise method). If there are no data for the location, a warning will be printed, and the program will use Edisto Experiment Station historical weather.

Weather File. Nine data points are stored for each day in the weather file. Data for up to 7 days are blocked in one record of 255 bytes. If a record contains less than 7 days, the data will be stored starting at the beginning of the record, and the unused space will be filled with blanks. The record format is given in table 3.

Each site has a weather file containing a name composed of the first five characters in the location name plus the extension "/ETP," thus giving a name of the form ". . . . . /ETP."

Site Parameters. The site file contains general information about the crop, soil characteristics, and WC. All site information is stored in the same file, where each record (of 255 bytes) corresponds to one site. The record format is shown in table 4.

Table 2.
Format for records in historical polynomial file

First byte[1]	Field length	Format	Contents
25*(I-1)+1	4	Character	Location first 4 letters
25*(I-1)+5	4	Real encoded	A0
25*(I-1)+9	4	Real encoded	A1
25*(I-1)+13	4	Real encoded	A2
25*(I-1)+17	4	Real encoded	A3
25*(I-1)+21	4	Real encoded	A4
25*(I-1)+25	1	Character	Carriage return
251	5	None	Not used

[1] I is the sequence number corresponding to the location and can have a value of 1 to 10.

Table 3.
Format for records in weather file

First byte[1]	Field length	Format	Contents
36*(I-1)+1	4	Character	Day of year
36*(I-1)+5	4	Character	TMAX
36*(I-1)+9	4	Character	TMIN
36*(I-1)+13	4	Character	TDEW
36*(I-1)+17	4	Character	Rain and/or irrigation
36*(I-1)+21	4	Character	Wind travel
36*(I-1)+25	4	Character	RAD
36*(I-1)+29	4	Character	PAN
36*(I-1)+33	4	Character	Potential ET
253	3	None	Not used

[1] I is sequence number of the day in the record and will range from 1 to 7.

Table 4.
Format for records in site parameter file

First byte[1]	Field length	Format	Contents
1	8	Character	Full site name
9	2	Int. encoded	Experiment year
11	20	Character	Investigator's name
31	2	Int. encoded	Planting date (day of year)
33	2	Int. encoded	50% emergence date (day of year)
35	12	Character	Variety
47	2	Int. encoded	Days of maturity
49	20	Character	Soil type (descriptive)
69	2	Int. encoded	No. of soil layers
69+(I-1)*16+1	4	Real encoded	Depth of layer #I
69+(I-1)*16+5	4	Real encoded	UL of available water, layer #I
69+(I-1)*16+9	4	Real encoded	LL of available water, layer #I
69+(I-1)*16+13	4	Real encoded	WC, layer #I
135	4	Real encoded	Row spacing
139	4	Real encoded	Plant population
143	2	Int. encoded	Last scheduling date (day of year)
145	4	None	Not used
149	2	Int. encoded	Date WC taken (day of year)
151	105	None	Not used

[1] I is the soil layer number and ranges from 1 to 4.

The site information for all sites will be stored in a file that will carry the name "SCHED/ALL," with each record in the file corresponding to one site.

Practical Use. A few pointers are given on the practical use of the program.

1. Keep each field as uniform as possible in all respects--soils, crop, weather.

2. Don't wait too late to begin running the scheduling program. You may miss critical periods. It is easier and more accurate to input data twice weekly than to try to catch up a month.

3. Reinitialize profile soil WC frequently--at least monthly, but preferably biweekly.

4. Study the output to become familiar with how each particular field and the program are behaving.

RESULTS AND DISCUSSION

The water budget program we have described has been used to schedule irrigations for 41 different fields at 5 locations during 1979, 1980, and 1981, as described elsewhere in this report. Some results have been good; others have not.

Better results have come from fine-textured soils, frequent reinitialization of WC profile, and following the recommended schedule unless rain fell during the forecast period. Poorer results have been caused by several factors. Practical estimation of UL and LL for coarse-textured soils has been difficult. One cooperator believes that field evapotranspiration rates often exceed potential rates in the size fields he used.

The relationship between actual and potential evapotranspiration rates as influenced by soil moisture was estimated. Lysimeter studies are needed to improve our estimate of the relationship. The Jensen-Haise method of calculating potential evapotranspiration has not been verified in humid areas. Again, lysimeter studies are required.

The water budget method and results are reasonable, but additional experience, research data, and user interface are necessary before the program can be successfully released to the end user. Several chapters of this report present the results of using this model in greater detail.

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3. WEATHER FORECASTS FOR IRRIGATION SCHEDULING

Milton E. Brown[1]

INTRODUCTION

Weather radar, analysis and prognostic charts; satellite pictures; and numerical forecast data from computers are all tools used to forecast weather in quantitative terms. The intent of this paper is to briefly describe these forecast procedures, describe the procedures used to provide biweekly weather forecasts for this research project, and emphasize problems encountered in forecasting weather parameters for scheduling irrigation in the Southeastern Coastal Plain. New National Weather Service (NWS) guidance material which was made available after the project was initiated is also described.

Although the Weather Service Forecast Office (WSFO) at Columbia, SC, began issuing operational agricultural weather forecasts in 1963, not all parameters needed for the computer-based water-balance (CBWB) procedure were available (Brown and Lambert 1981). The CBWB procedure required a 5-day forecast of maximum and minimum temperature and incoming solar insolation. The temperature forecast was obtained directly, but the prediction of incoming solar radiation was a new challenge for most NWS offices, especially the WSFO in Columbia, SC.

FORECASTS FOR FIVE LOCATIONS

Sites for which forecasts were needed were agricultural experimental stations at Clayton, NC; Blackville and Florence, SC; Tifton, GA; and Gainesville, FL.

Normally, a weather service forecast office only issues forecasts for the coastal waters and State in which it is located; however, WSFO, Columbia, agreed to make an exception and forecast for all sites. This simplified the mechanics of the CBWB procedure by allowing Clemson University, which ran the computer model, to deal only with one forecast office.

Forecasts were issued for a 5-day period twice weekly, on Monday and Thursday, primarily during the growing season.

TEMPERATURE FORECASTS

Model output statistics (MOS) obtained from the National Meteorological Center (NMC), Camp Springs, MD, and zone forecasts for each of the four States were used in the forecast for the first 2 days of the forecast period (Glahn and Lowery 1972, NWS 1981). Extended forecast charts (figs. 1, 2) were used for the remaining 3 days. Temperature anomalies indicated the expected departures from normal of maximum and minimum temperatures for days 3, 4, and 5. The surface and upper-level prognostic charts were used to further refine the temperature predictions.

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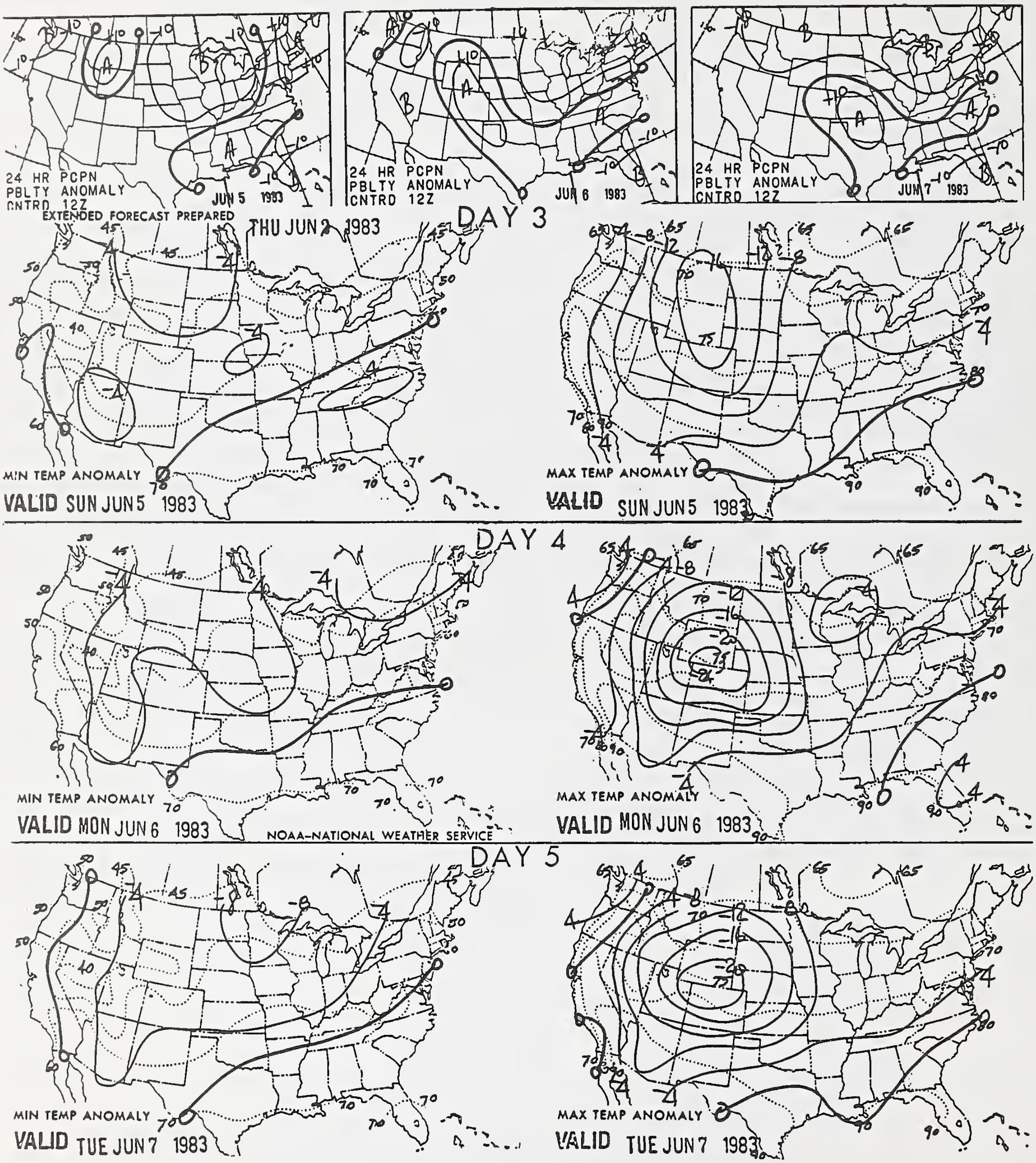

Figure 1.
Extended forecast chart showing precipitation and temperature anomalies for days 3, 4, and 5. The three panels at the top depict areas where the probability of precipitation is above or below long-term normals (+10 means 10% above normal). The temperature anomalies show the departure from normal of the maximum and minimum temperatures.

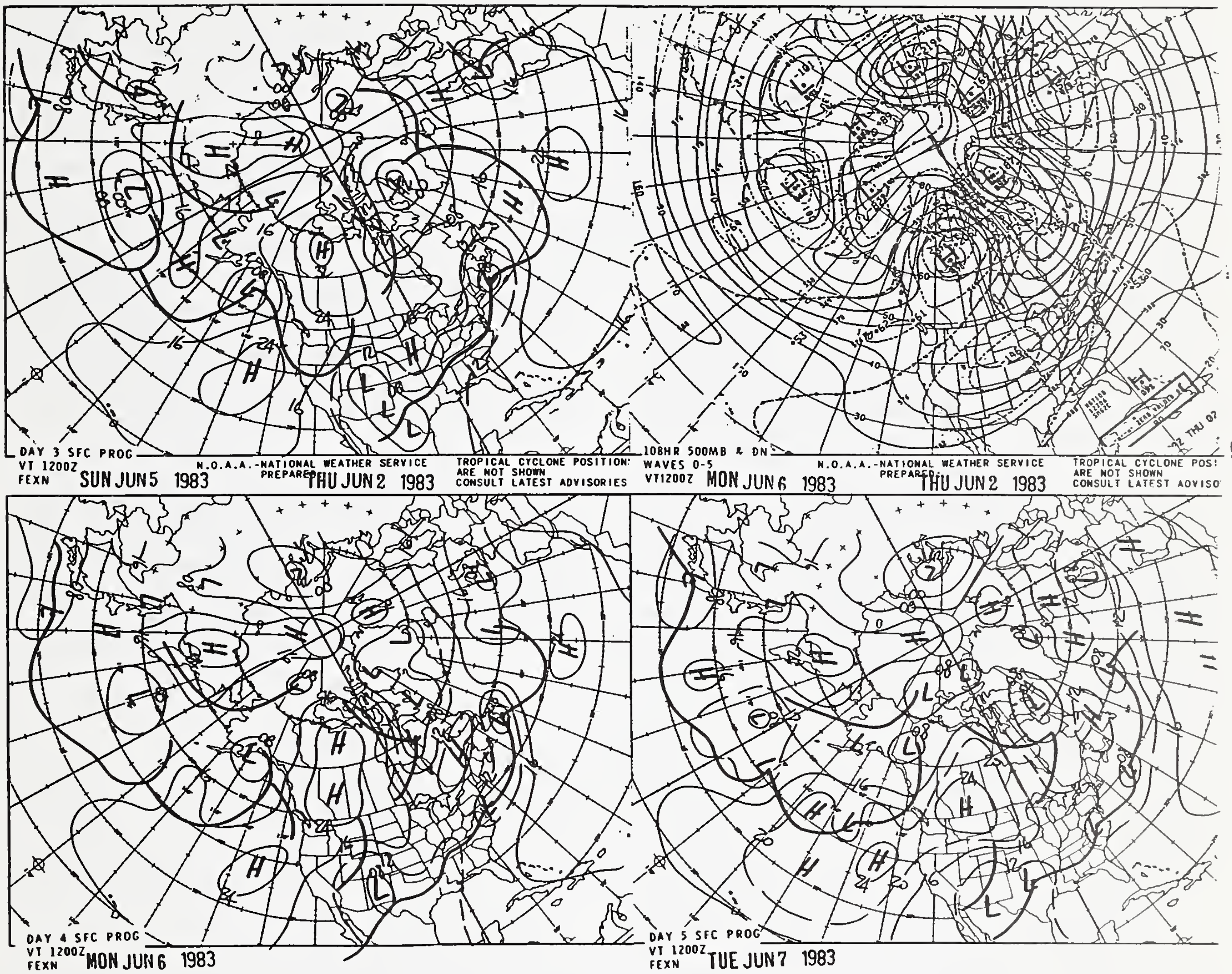

Figure 2.
Extended forecast chart of surface and upper air features. The surface prognostications are for days 3, 4, and 5 while the 500-millibar chart (approximately 18,000 feet above the surface) is valid at the midpoint of the 3-day period.

SOLAR RADIATION FORECASTS

When the irrigation scheduling project began in 1979, National Meteorological Center guidance for South Carolina agricultural forecasts (fig. 3) was used (Jensenius et al. 1979). This included daily prediction of solar radiation for 3 days. It was discovered while using this guidance material that the forecasted incoming radiation values on clear days were often as much as 150 langleys below the observed values. Further investigation traced the problem to the input solar radiation data used in calculating the regression equation to predict the daily values. Inaccurate data were due to class B instruments and the lack of a routine recalibration schedule. Without the benefit of reliable solar radiation guidance, MOS was used to forecast cloud cover for days 1 and 2 (NWS 1982). These values were compared with those for similar days in the recent past to arrive at a prognosis of incoming solar radiation in langleys per day.

Forecasts for days 3, 4, and 5 were most subjective, since the extended forecast charts (figs. 1, 2) were the only guidance material available. In some cases, weather features followed continuity, and predictions were not difficult. In other cases, long-term means appeared to be as good as any other known forecast (USDC 1980). There were also periods when weather systems were stationary, and small day-to-day changes occurred.

Over the growing seasons of 1979, 1980, and 1981, we found that on clear days with low turbidity, a reasonable prediction was approximately 125 langleys above normal. A hazy, cloudless day with surface visibility of 2 to 3 miles often dropped the incoming solar radiation as

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ZCAC 899
AXUS 52 KWBC 210000
AG WEATHER GUIDANCE /MOS/ 05/21/79  0000GMT  SOUTH CAROLINA
                  DATE   22   22   23   23   24   24   25   25
                   GMT   00   12   00   12   00   12   00   12

ALLN AIR      MX/MN      85   65   85   65   83   64   82   59
     GRASS    MX/MN      78   73   79   73   79   73   78   73
     POPA/24 HR            54321     65431     65421

BLAK AIR      MX/MN      85   64   85   65   84   63   83   58
     BARE     MX/MN      79   72   78   71   79   72   81   71
     INSOL              385       324       332
     POPA/24 HR/           54311     65431     65321

CLEM AIR      MX/MN      81   61   81   62   81   61   80   57
     BARE     MX/MN      79   71   79   71   79   71   80   70
     INSOL              312       269       315
     POPA/24 HR            75321     86542     64321

FLRN AIR      MX/MN      83   64   82   65   82   65   80   59
     BARE     MX/MN      75   68   75   68   76   69   76   68
     POPA/24 HR/           54321     75431     65421
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Figure 3.
Agricultural weather guidance for May 21, 1979, for four selected South Carolina locations.

low as 80 langleys below the normal value. Heavy clouds usually limited daily solar insolation to a value less than 100 langleys.

NEW SOLAR ENERGY GUIDANCE

In late October 1981, the NWS began issuing solar energy estimates (fig. 4) (Jensenius 1983, NWS 1981). These forecast charts provided guidance for days 1 and 2, and often a trend into day 3. Justus and Tarpley (1983) examined predictions at Atlanta, GA, and found the root mean square error to be 25% and 28% for the 24- and 48-h prognosis for a 14-month period in 1981 and 1982, respectively. A forecast based upon persistence of observed insolation from one day to the next was only 47% accurate for the same period in Atlanta, while a forecast based upon the long-term observed monthly mean was 39% accurate.

PRECIPITATION FORECASTS

Precipitation forecasts were neither provided to the locations nor utilized by managers in making decisions regarding irrigation applications during the 3-year period of the regional study. Following completion of the 3-year regional study, certain locations continued to use the CBWB procedure in order to complete experimental objectives or to collect data for improving the model in similar experiments. In connection with these continuing studies, the WSFO, Columbia, was asked to include a 24-h rainfall prediction, 8 a.m. to 8 a.m., for the growing seasons of 1982 and 1983. Precipitation forecasts were conservative by design and were included to see if they might improve the efficiency of irrigation water use.

The NMC quantitive precipitation forecasts were used for days 1 and 2, but if the probability of precipitation was 20% or less, no rainfall was forecast. For probabilities from 30 to 40%, a trace would normally be predicted to indicate the possibility of scattered showers. Seldom was more than 13 mm forecast for a probability of 50 to 60%. For values of 70% and above, forecasts were less conservative. Rainfall probabilities for days 3, 4, and 5 were less than 40%, except in a few cases.

CONCLUSIONS

The need for weather forecasts in this irrigation scheduling research project helped to develop new forecasting skills and also gave a greater insight into meteorological needs for another phase of agriculture. The introduction of new NMC solar energy guidance technology greatly aided the project. Satellite estimates of daily solar radiation (fig. 5), with an error of less than 10%, can be made available whenever the need arises. They should be of great value in scheduling irrigation and in other types of crop modeling (Tarpley 1979).

It is important that user needs be identified to NWS regional and national headquarters and to the Technical Development Laboratory (TDL), so that the information required may be developed and applied without delay. The TDL was responsible for the solar energy guidance and is capable of generating other types of meteorological guidance from the limited-area fine-mesh model and MOS.

ACKNOWLEDGMENTS

The author thanks John C. Purvis, meteorologist in charge, who helped prepare these forecasts until his retirement in December 1981, and his successor, Bernard L. Palmer, who issued forecasts on many occasions during later growing seasons. Without their cooperation, WSFO, Columbia, would have been unable to participate in this project.

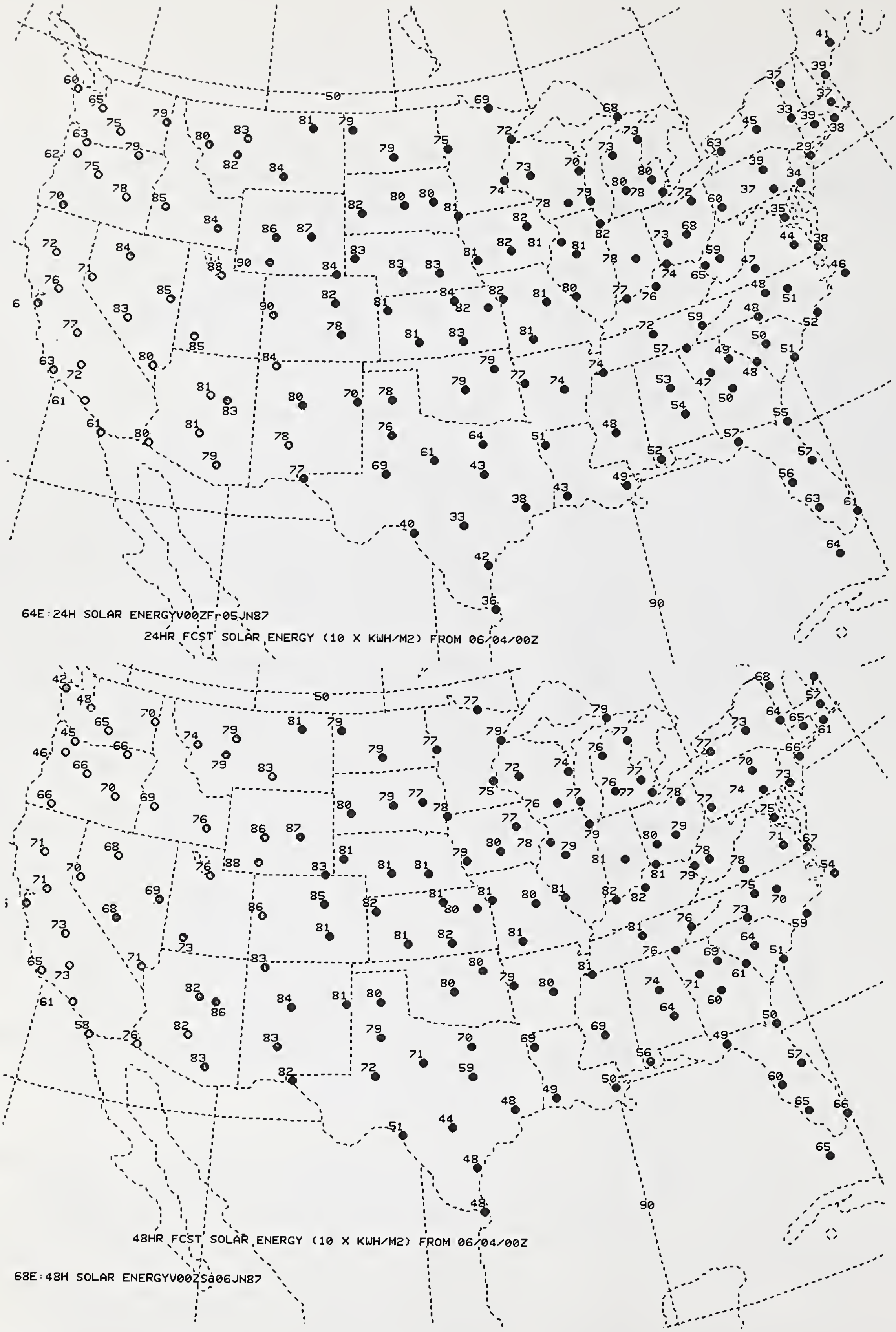

Figure 4.
Solar energy forecast guidance charts are 24-h forecast for day 1 and 48-h forecast for day 2. The chart values are 10 times the actual values. To convert to langleys, multiply the chart value by 8.6.

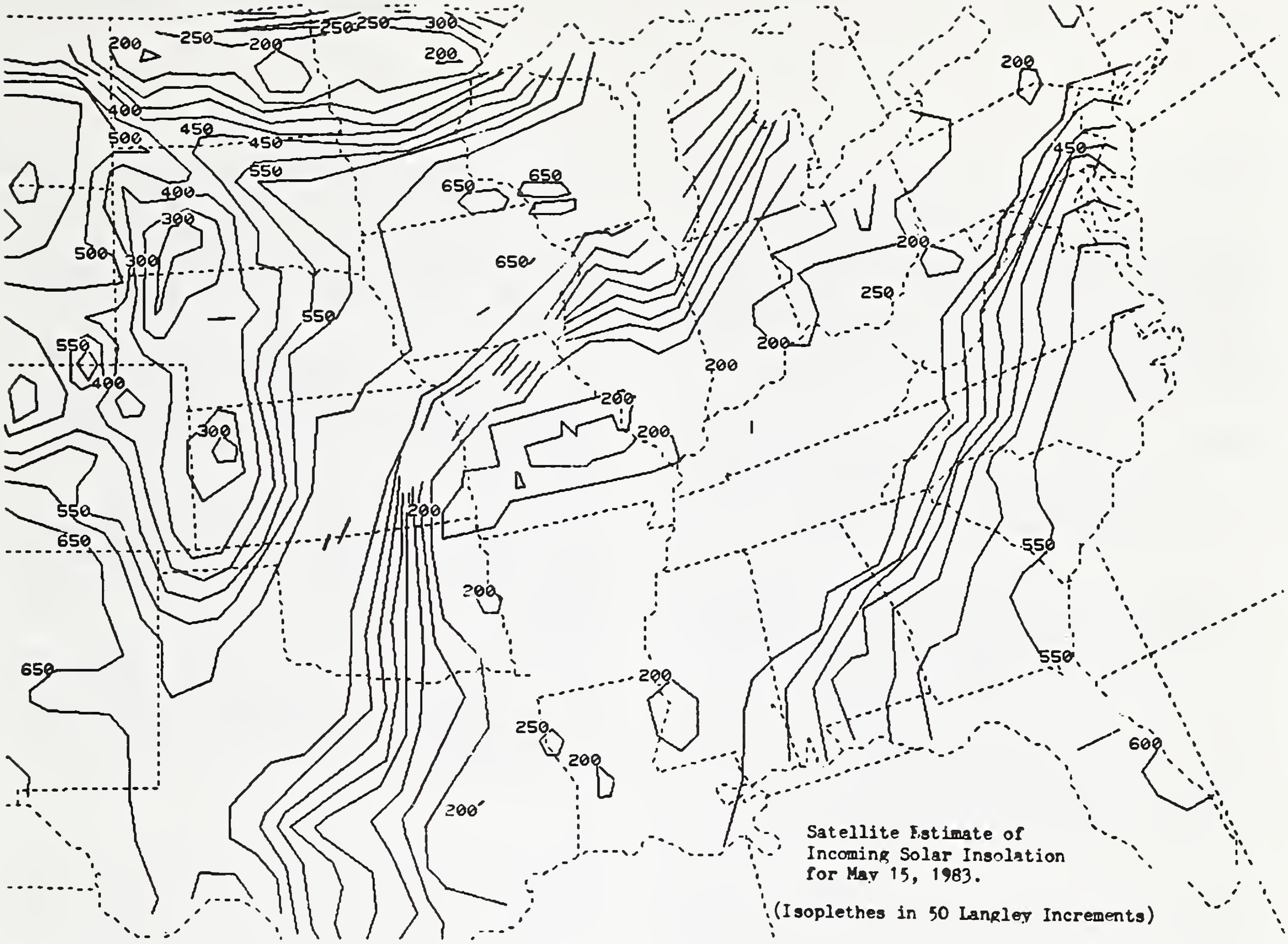

Figure 5.
Incoming solar insolation, as estimated from satellite pictures.

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4. CLAYTON, NORTH CAROLINA

D.K. Cassel[1]

INTRODUCTION

North Carolina is located in the humid, temperate region of the United States and lies between 33 and 37 degrees latitude and 75 and 85 degrees longitude. The State can be divided into three physiographical provinces: the Appalachian Mountains in the west, the Piedmont in the center, and the Coastal Plain in the east. Mean July temperatures range from 15 to 27°C in the Coastal Plain and Piedmont provinces (Hardy and Hardy 1971). Mean annual January temperatures range from -2 to 5°C in the mountains, 5 to 7°C in the Piedmont, and 5 to 9°C in the Coastal Plain. The mean annual frost free period is 186 days at Asheville (mountains), 198 days at Greensboro (Piedmont), and 216 days at Goldsboro (Coastal Plain).

The factor most limiting to crop production in North Carolina is drought induced water stress. This is true even though mean annual precipitation exceeds mean annual evapotranspiration at all locations in the State. Water stress occurs during periods when the amount of rainfall is below average or when it is poorly distributed. Mean annual precipitation ranges from 1200 to 2050 mm in the mountains, 1100 to 1250 mm in the Piedmont, and 1250 and 1450 mm in the Coastal Plain. Mean monthly precipitation is more or less equal throughout the year with the exception of July and August, which have higher rainfall. Yet, it is during these higher rainfall months and in June and September when water stress of field crops occurs.

Many soils on the Atlantic Coastal Plain have tillage pans which restrict the rooting depth of important agricultural crops. Restricted root growth increases the magnitude of water stress. Farmers have used deep tillage techniques such as subsoiling and chisel plowing to disrupt the tillage pan in an attempt to increase rooting depth and uptake of water stored below the tillage pan.

Use of irrigation in North Carolina to supplement rainfall on soils either with or without tillage pans has increased dramatically during the past decade. Irrigated land increased from 45,000 ha in 1975 to an estimated 78,000 ha in 1983. Furthermore, it is estimated that growth of irrigated hectarage will increase at the rate of 4 to 5% annually during the next decade (Ronald Sneed, personal communication, North Carolina State University). Hectarages of irrigated crops in descending order are tobacco, corn, peanuts, and vegetables.

Because irrigation water supplies are limited in North Carolina, farmers need to use irrigation water efficiently. Current sources of irrigation water are farm ponds (73%), streams (20%), and groundwater (7%) (Ronald Sneed, personal communication). Presently, few irrigators rigorously follow irrigation schedules. It is anticipated that the adoption of irrigation schedules will result in higher yields, less water used per hectare, and greater profits.

The objectives of this study were to evaluate a computer-based water balance (CBWB) technique and a tensiometer (TENS) technique for scheduling irrigation of corn on a Coastal Plains soil having a tillage pan and to determine if irrigation schedules are dependent upon the tillage regime.

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METHODS

This irrigation-scheduling/tillage-interaction study was conducted in 1979, 1980, and 1981 on the Atlantic Coastal Plain at the Central Crops Experiment Station near Clayton, NC. The field was composed primarily of Wagram loamy sand (loamy, siliceous, thermic Typic Paleudult). Throughout this chapter, the soil will be referred to as "Wagram." It had a 0.25-m-thick Ap horizon; the E horizon thickness varied from a few millimeters to 0.3 m, and a traffic-induced tillage pan existed in its upper portion. Soil physical properties associated with the tillage pan at this location have been described by Cassel et al. (1978). A brief description of the Wagram soil profile is presented in table 1.

The experimental design was a split plot with four replications. The six main effect treatments were all combinations of two tillage practices and three water management levels. Table 2 summarizes the tillage and irrigation practices for each treatment and defines the symbols used hereafter to refer to each treatment. The entire field was disked once prior to imposing the tillage treatments.

Conventional (or normal) tillage, denoted by N followed by a number for water management treatment, consisted of disking two times immediately before planting. Subsoil tillage, denoted by S, consisted of in-row subsoiling to a depth of 0.45 m, with 50-mm-wide shanks spaced 0.95 m apart. Subsoiling was followed by a bedding operation, whereby a mound of soil about 0.15 m high was formed over the subsoil slit. Subsoiling and bedding operations were performed either on the date of planting or several days prior to planting.

Subplot treatments (table 2) in 1979 and 1980 were timing of nitrogen topdressing. In 1981, each tillage treatment was split differently. Splitting the subsoiled plots allowed an evaluation of the carryover effects of subsoiling from the previous year. All plots in 1981 received split N topdressing applications totaling 196 kg/ha N.

Pioneer 3369A corn (*Zea mays*) was planted in 0.95-m-spaced rows on 18 and 19 April in 1979 and 1980, respectively. In 1981, Pioneer 3320 was planted on 16 April. Mean plant populations across all treatments were 64,200, 62,700, and 70,400 plants/ha for 1979, 1980, and 1981,

Table 1.
Wagram soil profile description

Horizon	Depth(m)	Munsell Color	Texture	Comments
Ap	0 - 0.25	10 YR 4/3	ls	single grain, very friable
E	0.25 - 0.51	10 YR 6/4	ls	single grain, very friable
B21t	0.51 - 0.97	10 YR 5/8	scl	subangular blocky, very hard, firm
B22t	0.97 - 1.35	10 YR 5/8	scl	weak medium platy parting to weak, medium subangular blocky; very hard, firm

Table 2.
Definitions of treatments for main effects and subplots

Treatment	Symbol	Comments
Main effects		
Normal-dryland	N1	Conventional tillage, no irrigation water applied.
Normal-CBWB	N2	Conventional tillage, irrigation water applied based on computer-based water balance.
Normal-TENS	N3	Conventional tillage, irrigation water applied based on tensiometers.
Subsoil-dryland	S1	Subsoiled, bedded, no irrigation water applied.
Subsoil-CBWB	S2	Subsoiled, bedded, irrigation water applied based on computer-based water balance.
Subsoil-TENS	S3	Subsoiled, bedded, irrigation water applied based on tensiometers.
Subplots		
	1979	
One N application		168 kg/ha N applied when corn was 0.25 m high
Split N application		84 kg/ha N applied when corn was 0.25 m high; 84 kg/ha N applied 3 weeks later
	1980	
One N application		196 kg/ha N applied when corn was 0.25 m high
Split N application		98 kg/ha N applied when corn was 0.25 m high; 98 kg/ha N applied 3 weeks later
	1981	
Cultivation		High One half of each plot in treatments N1, N2, and N3 received cultivation when corn was 0.5 m tall; Low No cultivation
Subsoil carryover		High One half of each plot in treatments S1, S2, and S3 was bedded in 1981 but not subsoiled; Low The other half was bedded and subsoiled in 1981

respectively. Fertility and herbicide regimes for each year are shown in table 3. Starter fertilizer was applied in bands at planting at the rate of 28 kg/ha N and 56 kg/ha P_2O_5 for the 3 years and 112 kg/ha K_2O for 1979 and 142 kg/ha K_2O for 1980 and 1981.

Irrigation Scheduling Using Tensiometers

Irrigations for treatments N3 and S3 were scheduled based upon soil water pressure (SWP) readings obtained near the center of each plot using model 2710 Soiltest tensiometers. For treatment N3, tensiometers were installed 0.23 m away from the row, with the center of the tensiometer cup at the 0.25-m depth, that is, at the top of the tillage-induced pan. For treatment S3, tensiometer cups were placed at the 0.30-m depth. Irrigation water was applied to all four replications of a treatment when the mean SWP for all four replicate tensiometers decreased below -60 kPa in 1979 and below -40 kPa in 1980 and 1981. The amount of water applied per irrigation was measured in each plot using two rain gauges installed at a height of 2.4 m. Approximately 25 mm was applied at each irrigation.

Table 3.
Fertilizer and pesticide regimes for each year of the study

Additive	Year 1979	1980	1981
N (at planting)	28 kg/ha as NH_4NO_3	28 kg/ha as NH_4NO_3	28 kg/ha as NH_4NO_3
(top dress)	168 kg/ha as NH_4NO_3	196 kg/ha as NH_4NO_3	196 kg/ha as NH_4NO_3
P_2O_5 (at planting)	56 kg/ha as CSP*	56 kg/ha as CSP	56 kg/ha as CSP
K_2O (at planting)	56 kg/ha as KCl	71 kg/ha as KCl	71 kg/ha as KCl
	56 kg/ha as K_2SO_4	71 kg/ha as K_2SO_4	71 kg/ha as K_2SO_4
Butylate**	3.82 kg/ha a.i.	3.82 kg/ha a.i.	3.82 kg/ha a.i.
Simazine	2.28 kg/ha a.i.		2.28 kg/ha a.i.
Atrazine		2.28 kg/ha a.i.	

* CSP = Concentrated superphosphate.
** All herbicides incorporated by disking prior to applying tillage treatments. Chemical names for butylate, simazine, and atrazine are S-ethyl diisobutyl-thiocarbamate; 2-chloro-4,6-bis(ethylamino)-s-triazine; and 2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine, respectively.

Irrigation water was applied with a solid set overhead sprinkler system. A sprinkler head was placed on a 2.4-m-high riser located at each of the four corners of each 12-m x 12-m plot and applied water over a quarter circle. Rainbird model No. 35 PJ-ADJ-TNT sprinklers having nozzles with 3.2-mm (1/8 inch) diameter openings were used. During a given irrigation event, water was first applied using two sprinklers located on opposite corners of the plot. After one-half of the irrigation water had been applied, these two sprinklers were turned off, and the remainder of the water was applied using sprinklers located at the remaining two opposite corners of the plot. The application rate of irrigation water was 6.5 mm/h; application rates exceeding this value resulted in water ponding on the soil surface.

<u>Irrigation Scheduling Using the Computer-Based Water Balance</u>

Treatments N2 and S2 were irrigated based upon the CBWB, which is described in chapter 2. Data inputs required for initializing the CBWB model were current crop rooting depth, in situ upper limit of available water (UL), lower limit of available water (LL), and soil water content (WC) for the various layers of the potential crop rooting zone at initialization, number of days after corn emergence, number of days from emergence to crop maturity, allowable soil water depletion, and the weather forecast for the next 5 days. As the corn plant continued to grow, the depth of rooting increased until the maximum rooting depth was reached. The CBWB considered this increase in rooting depth (and rooting volume) with time.

Soil water-holding properties for the 1.22-m deep profile of Wagram loamy sand are shown in table 4. In situ UL of the Wagram soil was determined using soil samples collected throughout the field 1 day after the soil profile had been thoroughly wetted by natural rainfall. The LL was considered to be equal to the -1500 kPa water content of disturbed soil samples from each soil horizon.

In 1979, a 75% allowable depletion value was used initially for treatments N2 and S2 but was changed to 65% for treatment S2 on 16 July. Allowable depletion was changed several times in 1980 and 1981 in an attempt to calibrate the CBWB for the Wagram soil. For treatment N2, allowable depletion began at 60% in 1980 and was changed to 65% on 15 June; for treatment S2, it was increased from 60 to 75% on 17 July. In 1981, allowable depletion was decreased from 60 to 50% on 10 June for both treatments. Weather forecast data

Table 4.
Soil water retention properties of Wagram loamy sand

Layer No.	Horizon	Depth	Bulk Density	In situ Upper Limit	Lower Limit	Available Water
		m	Mg/m^3	----------	m^3/m^3	--------
1	Ap	0 - 0.25	1.61	0.169	0.042	0.127
2	E	0.25 - 0.33	1.70	0.177	0.044	0.133
3	E	0.33 - 0.46	1.60	0.165	0.056	0.109
4	Bt	0.46 - 1.22	1.65	0.291	0.150	0.141

provided by the National Weather Service Office, Columbia, SC, and used as inputs included daily maximum and minimum air temperatures and daily total solar radiation.

During the remainder of the corn growing season, data inputs required to update the CBWB model were crop rooting depth, daily amounts of precipitation and irrigation, daily maximum and minimum air temperatures, and daily total solar radiation.

Output of the model included the following projections for the next 5-day period: Available water remaining in the crop rooting zone at the end of each day, percent soil water depletion for each day, and the date of the next irrigation, assuming no intervening rainfall.

Climatic Measurements

Many of the meteorological variables were measured using a Climatronics weather center. Air temperature was measured by thermisters (part No. 100093 mounted in a TA-IOWA motor-aspirated shield) and recorded each 15 s; daily maximum and minimum temperatures were extracted from this data base. Mean dewpoint temperature was measured hourly using lithium chloride cells. Wind speed was measured each 15 s at the 3-m elevation with a Mark III wind transmitter, averaged for each hour, and integrated over a 24-h period to give total daily wind run (km). Incoming total solar radiation was sensed continuously by an Epply model 8-48 pyranometer, and totaled each 15 s; these values were then integrated from sunrise to sunset. The above values were recorded at 24-h periods starting at midnight.

Rainfall for 24-h intervals beginning at 1700 h each day was measured using a standard Weather Bureau rain gauge. Evaporation from a standard class A National Weather Service evaportion pan was also measured for 24-h intervals beginning at 1700 h and used to estimate potential evapotranspiration. The quantity of irrigation water applied to each plot was measured using Tru-Check rain gauges installed between rows 6 and 7 and located 3 m from the boundaries of the plot. The height of these gauges was 2.4 m, the same height as the sprinkler heads. The quantity of irrigation water applied to each treatment on a given date was taken to be the mean of eight values (two measurements per plot x four replications per treatment).

Plant Parameters

Plant parameters measured during the growing season or at maturity were biomass of the above-ground vegetation, plant height, leaf area index, final plant population, number of earless stalks, grain yield at 15.5% moisture, and stover yield. Biomass, plant height, and leaf area index were determined at 10- to 14-day intervals. Before tasseling, height from the soil surface to the bend in the highest leaf of two random plants was measured. Later measurements included the tassel. Early in the season, leaf area of plants in 1 m of row was measured using a Lambda Instruments type LI-3050A leaf area meter. Biomass was also determined on this material. Beginning with the fourth sampling, biomass was determined on two randomly selected plants in each plot. Plant height and leaf area index on two plants per plot (Pearce et al. 1975) were also measured. Final plant population, number of earless stalks, and stover and grain yields were measured at maturity using plants hand harvested from 15 m of row per subplot.

Root length and root mass were estimated on 18 June and 9 July 1979. Soil samples were collected with a 76-mm-diameter bucket auger at the following depth increments: 0 to 0.10, 0.10 to 0.20,

0.20 to 0.30, 0.30 to 0.45, and 0.45 to 0.60 m. This series of five samples was taken at five positions on a transect perpendicular to the row in each plot. The positions were as follows: within the row; 0.48 and 0.24 m away from, and to one side of, the row (trafficked interrow); and 0.48 and 0.24 m away from, and to the other side of, the row (nontrafficked interrow). Because an extremely dense root mat existed in the 0- to 0.10-m-depth increment in the row position, no attempt was made to evaluate its length and mass. Soil samples were soaked in water and gently sieved under water to separate the roots from the soil particles. Root length was estimated using the line intersect method (Newman 1966). Roots were oven dried at $60^{\circ}C$, and root mass was determined.

After silking began, the ear leaf from 10 randomly selected plants in each subplot was harvested, dried, and ground. Total N and P were analyzed colorimetrically using a Technicon BD-4D unit after wet ash digestion of the sample (Technicon Industrial Systems 1974a, b). Corn grain was analyzed for N, P, and S. The plant material received a dry ash $MgNO_3$ treatment and was analyzed turbidimetrically after adding $BaCl_2$. Aflatoxin content of the harvested grain was analyzed by the Aflatoxin Laboratory at North Carolina State University.

Soil Parameters

Soil parameters measured at selected times during the growing season were gravimetric WC, volumetric WC, and cone index. (Cone index is defined as the force required to push a cone penetrometer into the soil divided by the projected cross-sectional area of the conical penetrometer tip (Davidson 1965).) Gravimetric WC was determined on soil samples taken 1 day after irrigation of treatments N2 and S2. Samples were taken from each of the four soil layers listed in table 4. These data allowed the CBWB model to be checked from time to time and reinitialized if necessary.

Reinitialization may be required from time to time throughout the growing season when the CBWB model no longer predicts the actual soil WC in the rooting zone as determined by actual soil water measurements. Possible reasons why the CBWB model might predict the wrong amounts of water in the soil are many. They include inaccurate measurements of soil parameters, such as in situ UL or LL; inaccurate plant parameter data, such as rooting depth or days to maturity; and inaccurate assumptions in the CBWB itself (see detailed discussion in chapter 7). If reinitialization is required often, the user must determine the source of the problem and take corrective action.

Volumetric WC was measured using a neutron probe (Troxler model 1255 soil moisture depth gauge connected to a model 2651 scaler-ratemeter). In 1979 one neutron meter access tube was installed in each main plot. In 1980 and 1981, one access tube per main plot was installed in two of the four blocks.

Cone index measurements to evaluate mechanical impedance were taken in 1979 using a Soiltest model CN-970 proving ring cone penetrometer. The penetrometer was equipped with a 12.8-mm-diameter cone having a 30° included angle. Measurements were taken within the following soil depth increments: 0 to 0.15, 0.15 to 0.30, and 0.30 to 0.45 m. The maximum penetrometer reading within each depth increment was measured in the row and 0.48 m on either side of the row, that is, in both the trafficked and nontrafficked interrows. Soil WC was measured adjacent to the location where penetrometer measurements were taken.

RESULTS AND DISCUSSION

Rainfall, Irrigation Water Applied, and Soil Water Balance

Weather conditions varied widely during the 3-year study. In general, 1979 was a wet year, while 1980 and 1981 were dry. Soil conditions and water requirements are reported by year.

1979. In 1979, dates and amounts of irrigation water applied to treatments N3 and S3 were unintentionally destroyed; however, the total amounts of irrigation water applied are presented in table 5, along with the complete set of data for treatments N2 and S2. Irrigation of conventionally tilled corn required 36 mm more water when scheduled by the CBWB than by TENS. For subsoiled corn, 11 mm more irrigation water was required by the CBWB.

Data pertinent to the soil water balance throughout a major portion of the growing season for treatment N2 are shown in figure 1. Daily rainfall and irrigation amounts are shown at the base of the figure. The water content (SWC) curve was calculated using actual weather data, not forecast weather data. Based on soil water retention data (table 4), 32 mm of available water could be held in the Ap horizon. An assumption in the CBWB is that soil water can be extracted to a depth 100 mm below the depth at which plant roots can be observed. For treatment N2, no roots were observed below 0.20 m, the depth of the tillage pan. Initially, an allowable soil water depletion value of 75% was selected.

The triangles below the critical level (CL) curve in figure 1 flag those days when irrigation was needed (based upon actual weather data) but was not applied. There are two reasons why irrigation water may not have been applied. First, irrigation scheduling was based upon data forecasted for solar radiation and air temperature, and these data may have deviated considerably from the actual weather which followed (and on which figure 1 is based). Second, irrigation was in fact scheduled by the CBWB but was not applied because of mechanical problems, which were encountered several times during 1979. The solid squares indicate field measured values of soil WC, which could have been but were not used to reinitialize the model, during 1979.

Soil water balance data for treatment S2 are also shown in figure 1. The crop rooting zone in subsoiled Wagram soil was deeper because the tillage pan was disrupted, thus promoting root penetration. For treatment S2, only one irrigation flag appears, indicating that the irrigations were timely. Only four irrigations were required for treatment S2 as compared with six for treatment N2.

Water content curves in figure 1 indicate that deficit irrigation occurred; that is, the soil water-holding capacity was not being completely refilled with each irrigation, but rather the water-holding capacity in the Ap horizon was being replenished (Cassel et al. 1985). Deficit irrigation is desirable in the humid, temperate Southeastern United States, where rainfall events are unpredictable. The unfilled water storage capacity remaining in the root zone after irrigation allows storage of water from rainfall should it occur soon after an irrigation event. The problem with deficit irrigation is that in conventionally tilled soil the total quantity of water stored in the crop rooting zone is already small; thus, irrigation may be required every 2 to 4 days (fig. 1) during periods with high evaporative demand. In arid and semiarid regions of the United States, rainfall events are less common during the growing season; thus the concern with heavy rainfall

immediately following irrigation is much lower. Consequently, the tendency is to completely refill the root zone with each irrigation.

Figure 2 shows WC measured by the neutron probe at depths of 0.15, 0.22, 0.30, 0.45, 0.60, and 0.75 m for treatments N1, N2, S1, and S2 during all or part of the growing season. Less soil water was present in treatment N2 than in treatment S2 at the 0.15-, 0.22-, and 0.30-m depths from late April to late June when irrigation began. During this same period, soil water content at depths greater than 0.30 m was greater for treatment N2 than S2. Compared with treatment N2, treatment N1 depleted more water in the 0.15-, 0.22-, and 0.30-m depths. At greater than the 0.45-m depth water was never utilized by treatment N1. Treatment S1 extracted much more water from the 0.22- and 0.30-m depths than did treatment N1. These data support the widely held idea that tillage pans decrease or prevent root penetration through them, thus denying to the plant the available water stored below the pan.

1980. In 1980, only 264 mm of rain fell during the growing season (table 6). The rainfall event on 27 and 28 June occurred at silking. The only other major rainfall occurred on 24 July. Combined rainfall for June and July was 144 mm as compared with 242 mm during the same period in 1979. Irrigation began on 3 June for treatments N3 and S3. Water was applied often to all irrigated treatments for the remainder of the growing season except for an approximately 2-week period during the latter half of June. Treatment N3 required 51 mm less irrigation water than the 237 mm used by treatment N2. Total amounts of irrigation water applied for the entire season for treatments S2 and S3 were identical, although the CBWB generally called for irrigation water to be applied on different dates from those of the TENS method. The 156 mm of irrigation water for the subsoiled treatments is only 59% of the amount required for treatment N2. The only difference in the CBWB inputs between treatment N2 and S2 was the depth of rooting.

Soil water balance information for treatment N2 is shown in figure 3A. Even though the rooting depth was deeper in 1980 than in 1979 (0.33 m vs. 0.20 m), irrigation water was applied as much as 1 to 4 days later. Limitations in this manner of data presentation were discussed earlier. A mechanical problem delayed for 4 days irrigation shown to be needed on day 57.

Figure 3B shows soil water balance data for treatment S2. Six irrigations were required for this treatment as compared with 10 for treatment N2. The crop rooting zone was deeper for the subsoiled treatment, thus providing greater available-water storage capacity. Again, it appears that irrigation was usually 1 day late. The implication is that when the water storage capacity in the root zone is refilled, there can be longer time intervals between irrigations. The only time during the growing season that the rooting zone was completely refilled, however, occurred on day 71 when rainfall followed an irrigation. Deficit irrigation, that is, incomplete refilling of the depleted portion of the water storage capacity by irrigation, on day 69 allowed most of the 51 mm of rainfall to be stored. Had the soil profile been completely refilled on day 69, this rainfall would have been lost to runoff, with possible soil erosion, or would have drained through the rooting zone, promoting leaching losses of mobile nutrients.

1981. Dates and amounts of rainfall and irrigation from planting to crop maturity are shown in table 7. The total rainfall for June plus July was about the same in 1981 as it was in 1980 (130 and 144 mm,

Table 5.
Dates and amounts of rainfall and irrigation water applied during the 1979 corn growing season, Clayton, NC

Date		Rainfall	Irrigation			
			N2	N3*	S2	S3*
		---------------------------mm---------------------------				
April	26	14				
	28	2				
May	4	13				
	5	13				
	10	37				
	12	3				
	14	54				
	19	34				
	22	2				
	23	1				
	24	21				
	25	19				
	26	1				
	29	3				
June	1	2				
	4	84				
	11	17				
	16	29				
	17	18				
	21	2				
	22	4				
	24	14				
	28		17			
	30	6				
July	3		20		20	
	4	4				
	6		23			
	7	2				
	10		23		25	
	15	14				
	16		28			
	18	4			28	
	19	1				
	20	1				
	21	19				
	23	5				
	24	2				
	25	8				
	26	6				
	30		27			
Aug	1				29	
	12	5				
Total		464	138	102	102	91

* Data showing amounts of irrigation on individual dates for treatments N3 and S3 were destroyed.

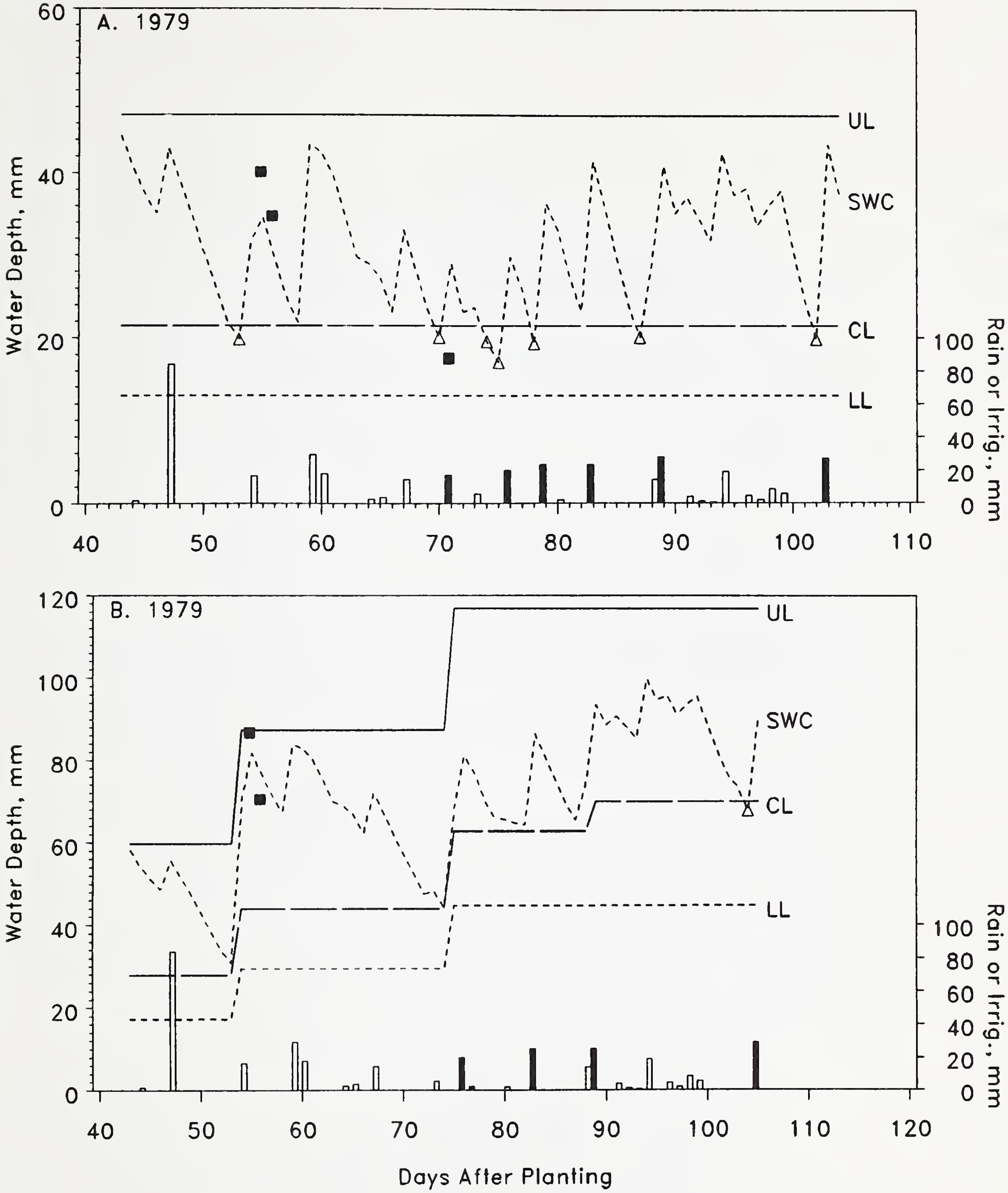

Figure 1.
Daily root-zone water content, irrigation, and rainfall data for (A) N2 treatment and (B) S2 treatment at Clayton in 1979. Curves show the simulated water content (SWC), the upper limit (UL) and lower limit (LL) of available water, and critical level (CL); and solid and open bars, respectively, show the amounts of irrigation (Irrig) or rain received; triangles flag days when CBWB indicated the need for irrigation; and solid squares show the measured water content. Scale for bars shown on right vertical axis.

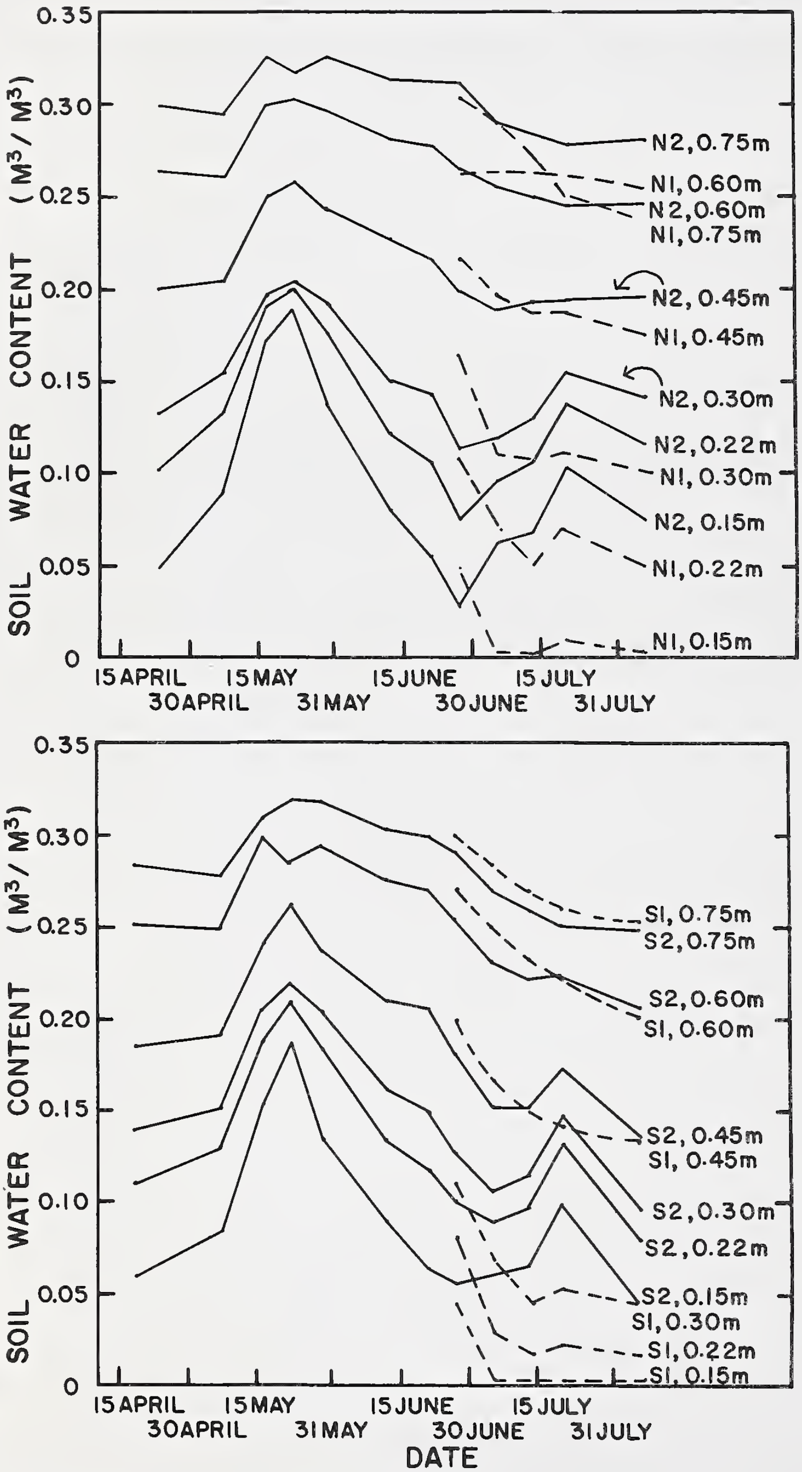

Figure 2.
Soil water content by depth and treatment during all or the last 40 days of the 1979 corn growing season: top, treatments N1 and N2; bottom, treatments S1 and S2.

Table 6.
Dates and amounts of rainfall and irrigation water applied during the 1980 corn growing season, Clayton, NC

Date		Rainfall	Irrigation			
			N2	N3	S2	S3
		-------------------------mm-------------------------				
April	28	32				
	30	5				
May	18	32				
	20	11				
	22	5				
	24	3				
	26	10				
June	3			10		10
	5		15	23	15	23
	7	6				
	10		34		34	
	13			26		26
	18		28			
	19	10		25		25
	25				28	
	26	21				
	27	28				
	28	2				
July	2			24		
	3		26			
	5	6				
	7					24
	8		26	21	29	
	9			14		
	10	5				
	12	2	20			
	14	2				
	15				24	
	16		23	22		23
	18	11	24		26	
	22			21		25
	23		22			
	24	44				
	28	2				
	30	5	19			
Aug	2	13				
	12	9				
TOTAL		264	237	186	156	156

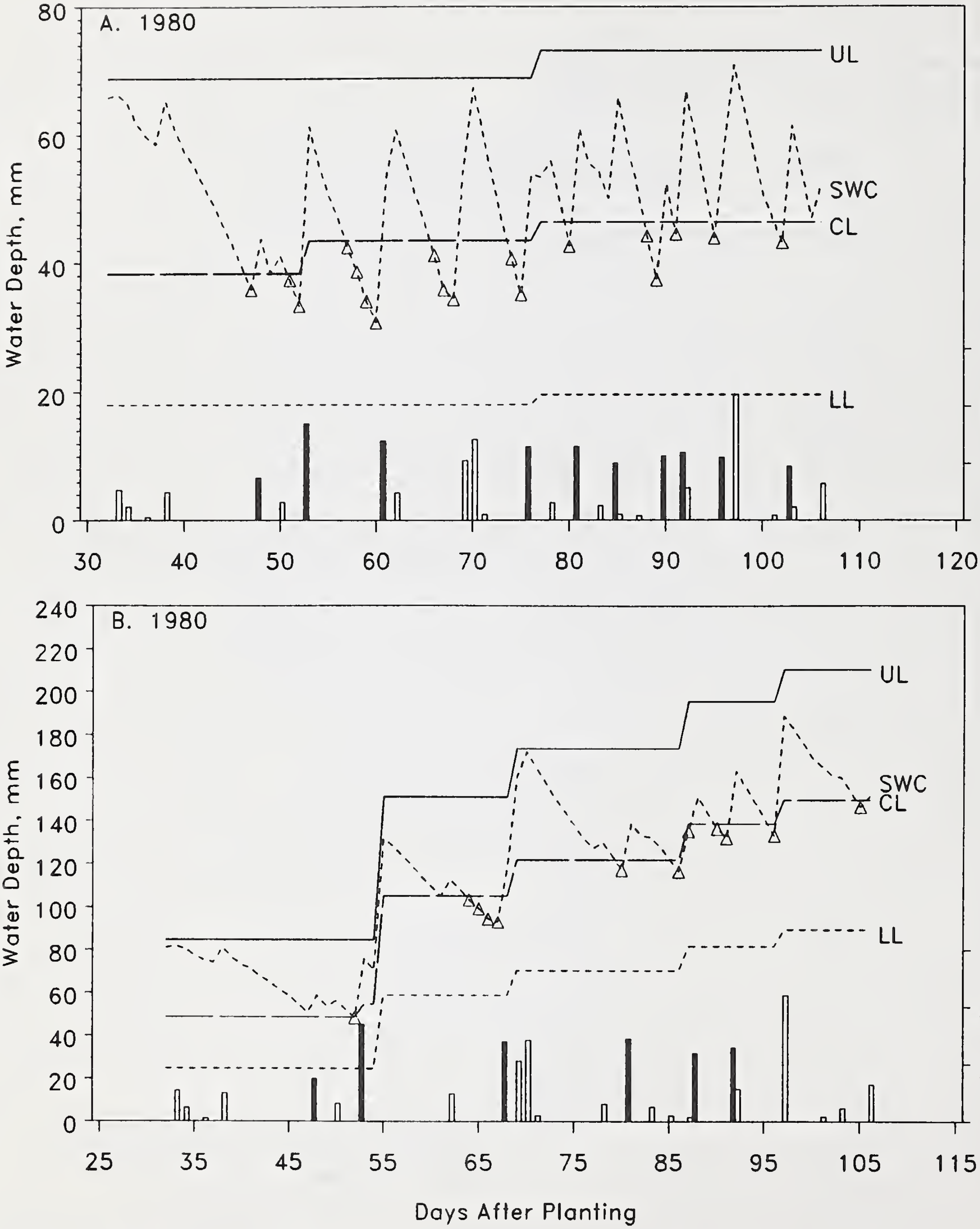

Figure 3.
Daily root-zone water content, irrigation, and rainfall for (A) N2 treatment and (B) S2 treatment in 1980. See figure 1 legend for explanation of symbols.

Table 7.
Dates and amounts of rainfall and irrigation water applied during the 1981 corn growing season, Clayton, NC

Date		Rainfall	Irrigation			
			N2	N3	S2	S3
		------------------------mm------------------------				
May	1	8				
	7	4				
	10	8				
	11	1				
	20	13				
	21	5				
	27	32				
	31	2				
June	6	20				
	11		38	38	38	38
	12	4				
	16			33		
	17		33		33	28
	19	3				
	23	1	31	31	31	31
	26	4				
	29		27	27	27	27
July	1	2				
	2	15				
	3	27				
	5	10				
	6	2				
	10		30	30		
	13				28	28
	15		25	25	25	
	16	7				
	17	1				
	20		3	3	3	3
	21	21				
	25	7				
	27		33	33	33	33
	29	3				
	30	7				
Aug	3	1	29	29	29	
	6	2				
	7		33			
	8	4				
	9	6				
	11				29	
TOTAL		220	282	249	276	188

respectively), but it was about 100 mm less in these 2 years than it was in 1979 (236 mm). June 1981 was very dry and received only 32 mm of rainfall. Only one rainfall event greater than 10 mm occurred after 5 July. Hence, the non-irrigated treatments were severely stressed during the ear filling stage, as indicated by the amount of irrigation water applied to all four irrigation treatments. Treatment N2 received 282 mm of irrigation water during the growing season; 54% of it was applied after 5 July. Of the 249 mm of irrigation water for treatment N3, 48% of it was applied after 5 July. The main difference in irrigation scheduling methods between treatments N2 and N3 was that treatment N3 did not need the final 33 mm of irrigation water that was required for treatment N2. Treatment S2 required 88 mm more irrigation water than treatment S3. However, subsoiling did not reduce the amount of irrigation water required when irrigation was scheduled with the CBWB (compare N2 vs. S2). During August, treatment S3 continued to utilize water stored in the rooting zone and did not require the final two irrigations required for treatments N2 and S2.

Water balance data for treatment N2 in 1981 are shown in figure 4A. A 50% allowable depletion value was used to trigger irrigations. Based on the weather forecast data, irrigation water should have been applied at 31, 33, and 34 days after planting. We chose not to irrigate on those early dates because it was obvious that the plants were not under stress. Irrigation water was first applied on day 58 and continued at approximately 5-day intervals throughout the remainder of the season. This pattern was interrupted by rainfall events on days 78 and 97. Toward the end of the season (after day 100), we purposely delayed irrigation 1 or 2 days because the soil surface was moist and the crop, with leaves dying and grain hardening, had little demand for water. The crop coefficient may need to be adjusted (see the discussion in chapter 7).

Water balance data for treatment S2 are shown in figure 4B. The 0.88-m-deep rooting zone could hold 135 mm of available soil water. The available water capacity of the soil profile was completely recharged only one time during the entire growing season. Irrigation water was applied before the soil WC was reduced to the 50% available water capacity value. Further fine tuning of the model would allow the available water to be depleted to the 50% level before irrigating.

Corn Grain and Stover Yields

Corn yield data for each year and 3-year means are presented in table 8. Analysis of variance for each plot parameter indicated no significant difference ($\alpha = 0.05$) between subplot factors for any of the 3 years. Hence, the two subplot values for each plot were averaged and the averages treated as whole plot values in the remainder of the statistical analyses.

Subsoiling without irrigation (S1) in 1979 resulted in a grain yield 123% greater than the 4.453 Mg/ha yield for treatment N1 (table 8). Plant water stress resulting from the droughty conditions during and after silking severely reduced grain yield for treatment N1. Corn roots in subsoiled treatment S1 were able to extract water at depths below the tillage pan, thus avoiding the severe plant water stress experienced by treatment N1. Irrigation of subsoiled treatments S2 and S3, regardless of scheduling technique, did not increase grain yield above that for treatment S1. In fact, in 1979 grain yield tended to decrease with increasing amount of irrigation water applied. Stover yield followed the same pattern as the grain yield. The stover yields for the three subsoiled treatments

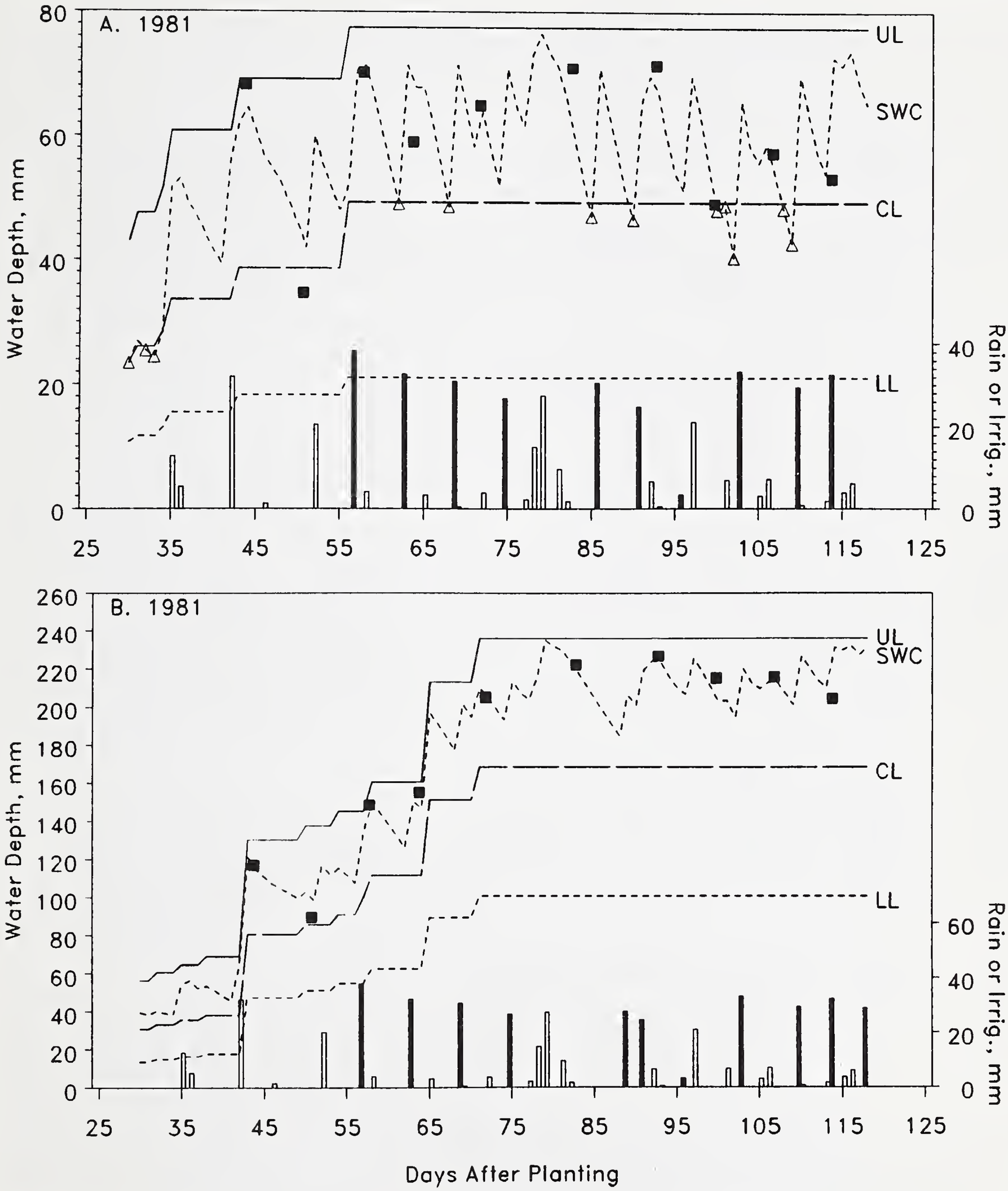

Figure 4.
Daily root-zone water content, irrigation, and rainfall for (A) N2 treatment and (B) S2 treatment in 1981. See figure 1 legend for explanation of symbols.

Table 8.
Yields of corn grain and stover, plant population, number of barren plants, and irrigation water use efficiency, as affected by water management and tillage on Wagram loamy sand

Treatment	Irrigation water applied	Grain	Stover	Plant Population	Barren plants	Irrigation Water Use Efficiency*
	mm	----Mg/ha----		----plants/ha-----		Mg/(ha•mm)
1979						
N1	0	4.453 c**	3.377 c	51,000	3,400 a	-
N2	138	6.648 b	4.014 bc	52,300	1,020 b	0.016
N3	102	7.150 b	4.588 b	51,000	1,020 b	0.026
S1	0	9.972 a	7.055 a	53,700	260 b	-
S2	102	9.408 a	6.287 a	53,700	430 b	-0.006
S3	91	9.722 a	6.556 a	53,700	510 b	-0.003
1980						
N1	0	1.863 c	2.866 d	60,300 c	24,800 a	-
N2	237	8.198 b	4.605 c	63,500 a	3,000 b	0.027
N3	186	8.586 b	4.713 bc	60,400 c	1,200 b	0.036
S1	0	8.144 b	5.466 b	62,900 ab	3,100 b	-
S2	156	9.005 ab	6.330 a	61,300 bc	1,400 b	0.006
S3	156	10.140 a	6.680 a	63,400 ab	1,800 b	0.013
1981						
N1	0	1.435 c	-	58,300 b	28,300 a	-
N2	282	8.342 a	-	61,100 ab	3,900 c	0.024
N3	249	8.683 a	-	62,400 a	3,700 c	0.029
S1	0	4.877 b	-	59,400 ab	14,400 b	-
S2	276	9.010 a	-	59,400 ab	4,000 c	0.015
S3	188	9.377 a	-	60,100 ab	4,100 c	0.024
Mean						
N1	0	2.584 c	3.122 c	56,500 b	18,800 a	-
N2	219	7.729 b	4.310 b	59,000 a	2,600 b	0.022
N3	179	8.140 b	4.651 b	57,900 ab	2,000 b	0.030
S1	0	7.664 b	6.261 a	58,700 a	2,400 b	-
S2	178	9.141 a	6.309 a	58,100 ab	1,900 b	0.005
S3	145	9.746 a	6.618 a	59,100 a	2,100 b	0.013

* Irrigation water use efficiency is grain yield of irrigated treatment less yield of nonirrigated treatment divided by irrigation water applied.

** Values followed by the same letter in a given column are not significantly different at the 5% level by the Waller-Duncan K-ratio t test.

were higher than those for the conventionally tilled treatments and did not reflect the differences in irrigation scheduling. No difference was found for the final plant (stalk) population at harvest for the six treatments, but treatment N1 had 233% or more barren plants than the other treatments.

Grain yield for all treatments except N1 was higher in 1980 than in 1979. The extremely dry growing season had a disasterous effect on the nonirrigated, conventionally tilled corn, which produced only 1.863 Mg/ha of poor quality grain. Irrigation of conventionally tilled soil, regardless of irrigation scheduling method, increased grain yields by 340% or more. Treatment S1 produced the same grain yield as treatments N2 and N3. Grain yields of treatments S2 and S3 were 383% and 444% greater than the yield of treatment N1. Increase in grain yield due to subsoiling alone (treatment S1) was greater in 1980 than in 1979. The higher grain yield in 1980 than in 1979, except for treatment N1, was due in part to higher plant populations in 1980. Plant population averaged across all treatments was 62,000 plants/ha in 1980 as compared with 52,600 in 1979.

Stover yields were similar to those in 1979. Exceptions were the yields for treatments N1 and S1 which were 0.511 and 1.589 Mg/ha, respectively, less than the corresponding 1979 yields. Water stress of nonirrigated treatments was greater in 1980.

The number of barren plants per hectare for treatment N1 was more than 700% greater than that for any other treatment. The large number of barren plants for treatment N1, 41% of the population, was expected because the plant population was much too high for nonirrigated production on a Wagram soil. Severe moisture stress throughout the growing season led to the high percentage of barren plants. An average of 3.3% barren plants was found for all other treatments combined.

In 1981, no differences in corn grain yield among the four irrigated treatments were found, although the subsoiled treatments tended to produce higher yields than the conventionally tilled ones. Treatment N1 had a poor grain yield of 1.435 Mg/ha; subsoiling without irrigation increased grain yield by 239%. Irrigation, regardless of scheduling technique or tillage method, effected an average yield increase of 515% over the yield for treatment N1. Stover was not harvested in 1981.

The plant population at harvest was lowest, as expected, for treatment N1. It experienced the most severe drought stress because of its restricted rooting zone. Forty-eight percent of the plants for treatment N1 were earless. Subsoiling alone reduced the number of earless stalks to 24%. Irrigation reduced the number of earless stalks across both tillage methods to an average of 6%.

The 3-year means for corn grain yields showed no yield advantage of either irrigation scheduling technique for a given tillage method. Irrigation of subsoiled Wagram, regardless of irrigation scheduling technique, produced higher grain and stover yields than irrigation of the conventionally tilled soil.

Irrigation Water Use Efficiency

Irrigation water use efficiency (IWUE) was calculated by

$$IWUE = \frac{YIR - YDR}{WIR}$$

where YIR and YDR are the corn grain yields of the irrigated and dryland treatments, respectively, for a given tillage treatment and WIR is the

irrigation water applied (table 8). The IWUE for all years was greater for the conventionally tilled treatment. For both tillage regimes, IWUE was greater when irrigation was scheduled using TENS. Hence, based on IWUE data alone, scheduling irrigation by TENS is superior to that by CBWB. Considering the 3-year average difference in irrigation water applied for the two scheduling techniques, 40 mm for conventional tillage and 33 mm for subsoiling, the amount of water conserved is small. Nevertheless, if irrigation water supplies are limited, this difference may be significant.

Leaf Area Index, Plant Height, and Biomass

Leaf area index, plant height, and biomass for selected dates during the 1979, 1980, and 1981 growing seasons are presented in tables 9, 10, and 11, respectively. In 1979, LAI for each treatment attained its maximum on 5 July (table 9). All subsoiled treatments had similar LAI values, and treatment S1 was significantly greater than all conventionally tilled treatments. For this same date, differences in plant height followed a similar pattern. Final plant height for all subsoiled treatments was significantly greater than the 2.2-m average height of the conventionally tilled treatments. Biomass results also followed this same pattern. On 18 July, the last date of measurement, biomass for the three subsoiled treatments was significantly greater than that for the conventionally tilled treatments.

In 1980, LAI was maximum on 27 June for all treatments except N1 (table 10). For this treatment, LAI was maximum 10 days later. Irrigation caused a greater increase in LAI for the conventionally tilled treatments than it did for the subsoiled treatments. Results of plant height and biomass data were similar to those for LAI.

In 1981, all treatments except N1 attained maximum LAI by 30 June (table 11). Irrigation of conventionally tilled Wagram increased LAI approximately 1 m^2/m^2 above the value for treatment N1. Subsoiling without irrigation increased LAI about 0.5 m^2/m^2 over that of treatment N1; irrigation of the subsoiled plots added an additional 0.5 m^2/m^2.

Irrigation of conventionally tilled treatments, regardless of irrigation scheduling method, increased plant height about 0.7 m over that of treatment N1. Subsoiling without irrigation increased plant height about 0.3 m; irrigation added another 0.5 m.

Subsoiling without irrigation increased total biomass at maturity (10 August) by 63% over the 8.842 Mg/ha value for treatment N1 (table 11). If corn silage had been the harvested product, treatments N2, N3, and S2 would have been equivalent. However, no differences in corn grain yield among the four irrigated treatments were found (table 8), although the subsoiled treatments tended to produce higher yields than the conventionally tilled ones. This tendency is opposite to that for biomass production.

Soil Mechanical Impedance

Mechanical impedance data for three dates in 1979 are presented as maximum cone indices (CI) at the midrow (M), row (R), and trafficked midrow (MT) positions for the conventionally tilled and subsoiled treatments in figure 5. The CI measurements shown were taken in the 0.15- to 0.30-m depth, where the tillage pan occurs. Cone index is known to be inversely related to Pw, the weight percent soil WC, which is shown in figure 5 for both conventionally tilled and subsoiled treatments for each date. No significant difference in WC between the

Table 9.
Leaf area index, plant height, and biomass of above ground vegetation for corn on Wagram loamy sand in 1979

Treatment	Date								
	5/15	5/25	6/1	6/11	6/21	7/5	7/6	7/18	7/23
Leaf area index									
	m^2/m^2								
N1	0.032	0.084	0.26 b*	1.52	2.17	2.22 b	-	-	1.76 c
N2	0.034	0.102	0.20 b	1.56	2.19	2.26 b	-	-	2.19 bc
N3	0.034	0.067	0.22 b	1.37	2.10	2.38 b	-	-	2.20 bc
S1	0.034	0.101	0.34ab	2.07	2.88	3.27a	-	-	3.16a
S2	0.040	0.101	0.30ab	1.89	2.68	3.02ab	-	-	2.79ab
S3	0.036	0.121	0.40a	1.65	2.52	2.73ab	-	-	2.65ab
LSD(0.05)	NS	NS	0.16	NS	NS	0.88	-	-	0.76
Plant height									
	m								
N1		0.40	0.48	1.05ab	1.41ab	2.13 c	-	-	2.15 c
N2		0.40	0.48	0.96ab	1.33 b	2.22 bc	-	-	2.23 c
N3		0.41	0.46	0.92 b	1.33 b	2.26 bc	-	-	2.29 bc
S1		0.44	0.54	1.19a	1.70a	2.73a	-	-	2.74a
S2		0.43	0.54	1.11ab	1.65a	2.64a	-	-	2.64a
S3		0.46	0.55	1.07ab	1.54ab	2.56ab	-	-	2.58ab
LSD(0.05)		NS	NS	0.24	0.30	0.35	-	-	0.32
Biomass									
	kg/m^2								
N1	6.2	0.016a	0.033a	0.168	0.253 c	-	0.589ab	0.652 c	-
N2	6.4	0.019a	0.032a	0.148	0.254 c	-	0.530 b	0.767 bc	-
N3	6.2	0.020a	0.028a	0.143	0.282 bc	-	0.791ab	1.007 b	-
S1	6.8	0.024ab	0.039ab	0.210	0.418a	-	1.020a	1.182a	-
S2	7.3	0.023ab	0.047ab	0.232	0.381ab	-	0.956ab	1.113a	-
S3	6.0	0.034 b	0.058 b	0.205	0.387ab	-	0.909ab	1.052ab	-
LSD(0.05)	NS	0.012	0.024	NS	0.114	-	0.447	0.328	-

* Values within a given column for a given parameter followed by the same letter are not significantly different at the 5% level by the Waller-Duncan K-ratio t test.

Table 10.
Leaf area index, plant height, and biomass of above ground vegetation at approximately 2-week intervals for corn on Wagram loamy sand in 1980

Treatment	Date						
	5/7	5/19	5/29	6/12	6/27	7/7	7/21
Leaf area index							
	m^2/m^2						
N1	0.02	0.25	0.95	1.77 d*	2.57 d	2.71 c	2.07 d
N2	0.03	0.29	0.96	2.55 bc	3.48 bc	3.39 b	3.30 bc
N3	0.02	0.24	0.77	2.32 c	3.37 c	3.30 b	3.15 c
S1	0.03	0.19	0.95	2.33 c	3.38	3.33 b	3.20 c
S2	0.03	0.31	1.09	2.68abc	3.73ab	3.56ab	3.48ab
S3	0.03	0.29	1.13	2.89a	3.83a	3.75a	3.68a
LSD(0.05)	NS	NS	NS	0.29	0.29	0.35	0.27
Plant height							
	m						
N1	0.12	0.29	0.65	1.04 c	1.23 d	1.71 d	1.70 d
N2	0.11	0.31	0.66	1.29 b	2.11 bc	2.43 b	2.43 b
N3	0.11	0.28	0.60	1.24 b	2.18 b	2.51 b	2.51 b
S1	0.11	0.29	0.64	1.24 b	1.89 c	2.22 c	2.22 c
S2	0.13	0.31	0.69	1.44a	2.27 b	2.56 b	2.56 b
S3	0.12	0.30	0.68	1.46a	2.58a	2.79a	2.80a
LSD(0.05)	NS	NS	NS	0.09	0.24	0.17	0.18
Biomass							
	kg/m^2						
N1	0.001	0.015	0.065	0.212 c	0.415 e	0.499 c	0.592 c
N2	0.001	0.017	0.075	0.314 b	0.674 cd	0.798 b	1.252 b
N3	0.001	0.014	0.055	0.240 c	0.629 d	0.785 b	1.146 b
S1	0.001	0.015	0.068	0.321 b	0.711 bc	0.839 b	1.179 b
S2	0.001	0.017	0.084	0.401a	0.788ab	1.022a	1.472a
S3	0.001	0.014	0.078	0.421a	0.861a	1.101a	1.493a
LSD(0.05)	NS	NS	NS	0.066	0.078	0.109	0.155

* Values within a given column for a given parameter followed by the same letter are not significantly different at the 5% level by the Waller-Duncan K-ratio t test.

Table 11.
Leaf area index, plant height, and biomass of above ground vegetation for corn on Wagram loamy sand in 1981

Treatment	Date								
	5/25	6/1	6/8	6/15	6/23	6/30	7/14	7/28	8/10
Leaf area index					m^2/m^2				
N1	0.27 b*	1.24	2.21	2.79 b	2.86 c	2.56 c	2.76 b	2.31	1.08 c
N2	0.40a	1.28	2.33	3.23a	3.68a	3.92a	3.76a	3.41a	2.22ab
N3	0.34ab	1.21	2.29	3.21a	3.60ab	3.91a	3.69a	3.52a	2.08ab
S1	0.33ab	1.23	2.32	3.04ab	3.29 b	3.20 b	3.17 b	2.84 b	1.65 bc
S2	0.33ab	1.12	2.23	3.31a	3.79a	3.94a	3.85a	3.53a	2.50ab
S3	0.33 b	1.24	2.37	3.40a	3.94a	4.07a	3.91a	3.73a	2.82a
LSD(0.05)	0.08	NS	NS	0.40	0.39	0.47	0.45	0.46	0.93
Plant height					m				
N1	0.36ab	0.68	1.19	1.59 b	1.68 d	1.68 d	1.77 d	-	-
N2	0.38a	0.66	1.24	1.70ab	2.20ab	2.55ab	2.57ab	-	-
N3	0.36ab	0.65	1.14	1.65ab	2.11 b	2.43 b	2.45 b	-	-
S1	0.36abc	0.68	1.15	1.63ab	1.91 c	2.04 c	2.12 c	-	-
S2	0.35 bc	0.65	1.15	1.74a	2.32a	2.68a	2.69a	-	-
S3	0.34 c	0.66	1.17	1.73a	2.30a	2.66a	2.67a	-	-
LSD(0.05)	0.03	NS	NS	0.13	0.16	0.19	0.16	-	-
Biomass					kg/m^2				
N1	0.026 b	0.112ab	-	0.444 b	-	0.511 c	0.762 c	0.913 c	0.884 d
N2	0.039a	0.122a	-	0.541ab	-	0.850ab	1.275a	1.843a	2.081a
N3	0.032ab	0.100ab	-	0.569a	-	0.980a	1.165ab	1.765a	1.929ab
S1	0.030 b	0.105ab	-	0.480ab	-	0.748 b	0.982 b	1.398 b	1.443 c
S2	0.030 b	0.090 b	-	0.519ab	-	0.910ab	1.307a	1.856a	1.825ab
S3	0.030 b	0.095ab	-	0.487ab	-	0.944a	1.337a	1.730a	1.780 b
LSD(0.05)	0.009	0.029	-	0.124	-	0.193	0.210	0.249	0.272

* Values within a given column for a given parameter are not significantly different at the 5% level by the Waller-Duncan K-ratio t test.

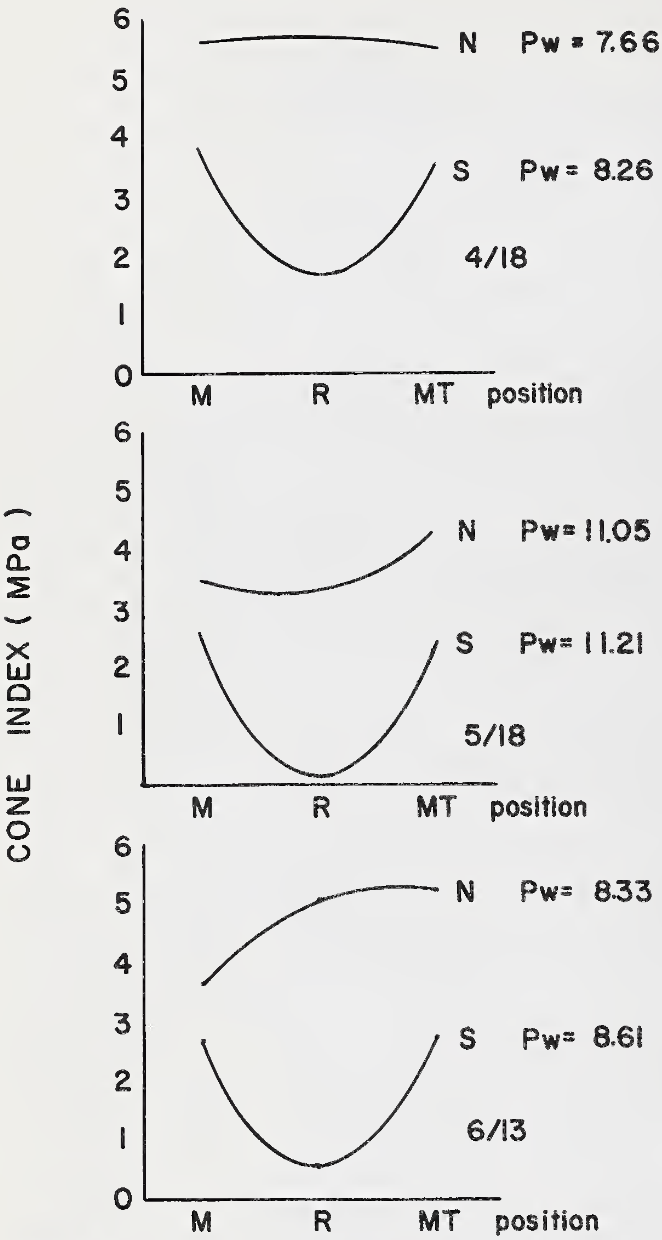

Figure 5.
Maximum cone index in the 0.15- to 0.30-m depth at three positions (M = midrow, R = row, MT = trafficked midrow) for conventionally tilled (N) and subsoiled (S) Wagram loamy sand on three dates in 1979. Also shown is the weight percent of soil water content (P_w) for N and S.

two tillage treatments occurred on any of the three dates. The CI values shown were unaffected by irrigation level because the first irrigation was not applied until after 13 June when the last measurements were taken. Maximum CI values for treatment N were greater than 3 MPa and were always greater for treatment N than for treatment S at every position. Values of CI greater than 2 MPa are considered detrimental to root proliferation (Taylor and Burnett 1964, Campbell et al. 1974).

Root mass and root length

Corn root mass and root length data for 18 June and 9 July 1979 are presented in table 12. Neither root mass nor root length on 18 June was affected by tillage. On 9 July, significant differences in both root mass and root length were found (table 12 and fig. 6). Root mass on 9 July was greatest for treatments N1, N2, and S1. Most root mass occurred above the tillage pan; no roots were observed below 0.45 m for treatment N1, whereas a root mass of 0.170 kg/m^3 was observed in the 0.45- to 0.60-m depth for treatment S2.

The greatest root lengths were associated with the nonirrigated treatments. Soil water stress promotes root proliferation, thus giving rise to greater root length and, possibly, greater root mass. Treatment S1 did not cause much soil moisture stress during the entire growing season, yet root length was not significantly different from the 5.57 km/m^3 value for treatment N1, which did cause severe stress. Corn root lengths for the four irrigated treatments were not significantly different from each other. Figure 7 shows the ratio of root mass to root length (g/m) for treatments N1 and S1 at three depths. The ratio was consistently greater for treatment N1 at all depths. Barley (1962) reported that the ratio of

Table 12.
Root mass and root length on 18 June and 9 July 1979 for corn on Wagram loamy sand

	18 June		9 July	
Treatment	Root mass	Root length	Root mass	Root length
	kg/m^3	km/m^3	kg/m^3	km/m^3
N1	0.0355*	2.42*	0.195a**	5.57a**
N2			0.170ab	3.42 bc
N3			0.096 bc	3.30 bc
S1	0.0409*	3.06*	0.124abc	4.81ab
S2			0.073 c	3.57 bc
S3			0.080 c	2.84 c
LSD(0.05)	NS	NS	0.084	1.31

* Values reported are means for all 3 treatments involving a given tillage method. Irrigation water was not applied until 28 June.
** Values in a given column followed by the same letter are not significantly different at the 5% level by the Waller-Duncan K-ratio t test.

root mass to length increases as resistance to root penetration increases. Presumably, in years having more severe droughts than those encountered in 1979, even greater differences in this ratio would occur between treatments.

Nutrient Contents of Grain and Ear Leaf and Aflatoxin in Grain

Total nitrogen and phosphorus concentrations in the corn ear leaf at silking; total nitrogen, phosphorus, and sulfur in the grain at harvest; and grain aflatoxin data are presented in tables 13 and 14. In 1980, no differences among treatments were found for nitrogen concentration in the ear leaf at silking (table 13). However, the phosphorus concentration was significantly less for treatment S1 for four of the five other treatment although levels for all treatments w in the reported sufficiency range (Plank 1979). Nitrogen concentration in the grain was highest for treatment N1, reflecting the low grain yield of this nonirrigated, conventionally tilled treatment. No differences in nitrogen concentration in the grain were found among the four irrigated treatments. No differences in phosphorus concentration in the grain was found, but sulfur concentration was highest in treatment N1.

The concentration of B1 + B2 aflatoxin was greatest for treatment N1 in 1980 (table 13). No differences existed among

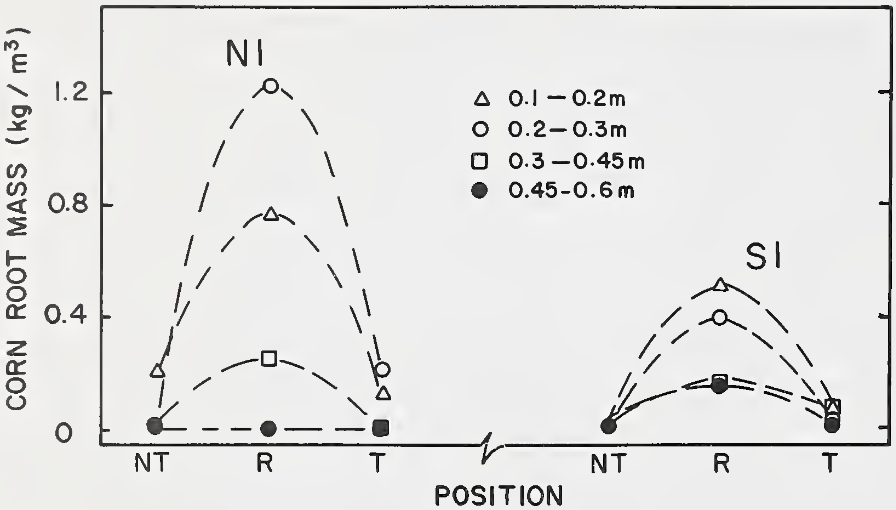

Figure 6.
Corn root mass on 9 July 1979 as affected by soil depth and sampling site (NT = nontrafficked interrow, R = row, T = trafficked interrow) for treatments N1 and S1.

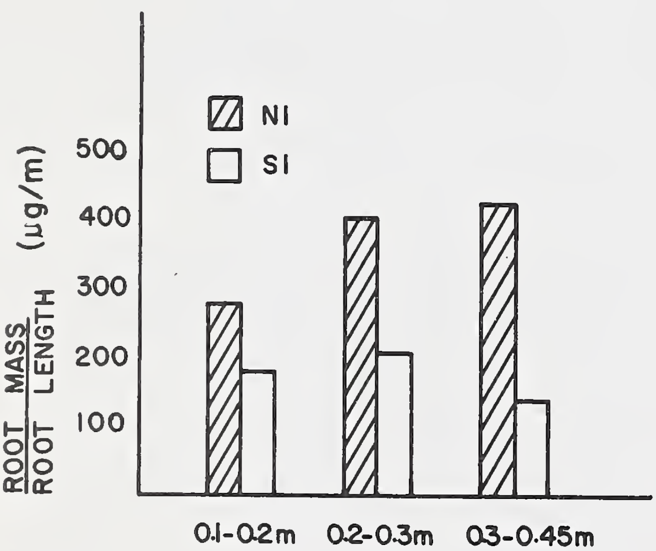

Figure 7.
Ratio of corn root mass to root length on 9 July 1979 at three depth increments for treatments N1 and S1.

Table 13.
Concentrations of selected nutrients in the corn ear leaf at silking and in the grain at harvest and aflatoxin levels in the grain at harvest, 1980

Treatment	N in ear leaf at silking	P in ear leaf at silking	N in grain	P in grain	S in grain	B1+B2 Aflatoxin
	-----------------------	----------------------	g/kg	------------------------		μg/kg
N1	32	3.6a*	14.1a	2.8	0.679a	94a
N2	31	3.8a	12.1 c	2.9	0.583 c	18 b
N3	30	3.5ab	12.5 bc	2.8	0.616 b	25 b
S1	30	3.2 b	12.9 b	2.7	0.606 bc	10 b
S2	31	3.8a	12.3 bc	2.9	0.601 bc	7 b
S3	31	3.8a	12.3 bc	2.7	0.613 bc	22 b
LSD(0.05)	NS	0.3	0.7	NS	0.029	25

* Values followed by the same letter in a given column are not significantly different at the 5% level by the Waller-Duncan K-ratio t test.

the remaining five treatments. Subsoiling without irrigation (treatment S1) was as effective in reducing aflatoxin infection as was irrigation with conventional tillage (treatments N2 and N3). Aflatoxin production is most prevalent when the corn plant undergoes severe stress. Corn grain cannot be marketed for certain uses if the aflatoxin levels exceed 100 μg/kg.

In 1981, treatments N1 and S1 had the lowest concentrations of nitrogen in the ear leaf at silking (table 14). Irrigation water was applied to all four irrigation treatments beginning 11 June. The rooting zone, that is, the upper 0.25 m of the soil profile, for treatment N1 remained very dry during this period. Uptake of nitrogen from this dry soil was retarded, giving rise to the low concentration 26.1 g/kg.

The upper 0.25 m of the soil in treatment S1 was also very dry, but roots utilized water stored below the disrupted tillage pan. Although the plants in treatment S1 produced 46% more biomass than treatment N1 at silking, the N concentration in the ear leaf for treatment S1 was as low as that for treatment N1 because the soil N was concentrated in the dry soil, where roots could not absorb it efficiently. Nitrogen concentration in the grain was inversely proportional to grain yield; no difference in N concentration among irrigated treatments was found.

Phosphorus levels for all treatments were sufficient. The lower phosphorus concentration in the ear leaf for treatment S1 than in N1 was the result of phosphorus dilution resulting from the 46% increase in biomass. The irrigated corn continued to absorb phosphorus from the wet Ap horizon.

Table 14.
Concentrations of selected nutrients in the corn ear leaf at silking and in the grain at harvest and aflatoxin levels in the grain at harvest, 1981

Treatment	N in ear leaf at silking	P in ear leaf at silking	N in grain	P in grain	Aflatoxin
	g/kg				µg/kg
N1	26.1 c*	2.8a	17.8a	3.0a	760a
N2	31.0 b	2.8a	14.2 c	2.9ab	72 b
N3	31.6 b	2.8a	13.8 c	2.9ab	47 b
S1	25.9 c	2.4 b	16.1 b	2.8ab	298ab
S2	32.9a	2.8a	14.1 c	2.8 b	50 b
S3	32.0ab	2.8a	14.2 c	2.8ab	17 b
LSD(0.05)	1.2	0.2	0.9	0.2	525

* Values followed by the same letter in a given column are not significantly different at the 5% level by the Waller-Duncan K-ratio t test.

Aflatoxin levels in grain at harvest for nonirrigated treatments N1 and S1 were exceptionally high and far exceeded the 100 µg/kg tolerance level for marketable grain. Subsoil tillage in 1980 was sufficient to prevent severe plant moisture stress, thus preventing toxic levels of aflatoxin to accumulate in the grain. In 1981, however, the drought severity was greater, and 760 µg/kg aflatoxin accumulated in treatment N1. Subsoiling alone decreased the aflatoxin level to 298 µg/kg, or 60% below the level for treatment N1. The drought severity was too great in 1981 for subsoiling alone to prevent severe soil moisture stress; consequently, treatment S1 had toxic aflatoxin levels. Irrigation, regardless of scheduling technique, decreased the aflatoxin level to 7% of the 760 µg/kg level for treatment N1.

SUMMARY AND CONCLUSIONS

The CBWB and TENS irrigation scheduling techniques were evaluated for corn at Clayton, NC, in 1979, 1980, and 1981. Both scheduling techniques were evaluated on conventionally tilled and subsoiled Wagram loamy sand which had a root restricting tillage pan at the 0.25-m depth. Summarized below are several specific results based on the 3-year study:

1. Both conventionally tilled and subsoiled Wagram soil responded to irrigation, regardless of the scheduling technique used.
2. Both the CBWB and TENS irrigation scheduling techniques worked adequately for corn on Wagram soil.
3. Approximately 30 to 50 mm of additional irrigation water was used when irrigation was scheduled by CBWB rather than by TENS.

4. Irrigation of conventionally tilled soil scheduled using CBWB resulted in corn grain yield increases ranging from 2.2 to 7.9 Mg/ha.
5. Irrigation of conventionally tilled soil scheduled using TENS resulted in grain yield increases ranging from 2.7 to 7.2 Mg/ha.
6. Irrigation of subsoiled Wagram soil scheduled using CBWB resulted in grain yield increases ranging from -0.6 to 4.1 Mg/ha.
7. Irrigation of subsoiled Wagram soil scheduled using TENS resulted in grain yield increases ranging from -0.2 to 4.5 Mg/ha.
8. Irrigation of conventionally tilled Wagram soil generally increased plant height, biomass, and leaf area index.
9. Irrigation alone and subsoiling alone reduced the level of aflatoxin.
10. Irrigation of subsoiled Wagram generally increased plant height, biomass, and leaf area index when compared with both nonirrigated conventionally tilled and nonirrigated subsoiled treatment.

Both irrigation scheduling techniques appeared to work well under the soil and climatic conditions at Clayton, NC. Selection of one irrigation scheduling technique over the other essentially becomes a matter of personal preference. The CBWB and the TENS irrigation scheduling techniques resulted in equal grain yields within each tillage regime. For the CBWB method, the frequency and amount of irrigation depend upon the allowable depletion value selected, whereas for the TENS method, these two factors depend upon the placement depth of the tensiometer and the SWP value at which irrigation is triggered. Based upon the average amount of water applied over the course of the 3-year study, the CBWB required 40 mm more water per year and one more irrigation per year than TENS. If irrigation water supplies are limited or the cost of water is high, this difference may be important. Associated with the water cost and availability are the price of energy required to apply the water and labor costs to provide the additional irrigation.

Use of either TENS or CBWB to schedule irrigation requires knowledge of the available soil water-holding capacity and the crop rooting depth. Both require periodic monitoring of soil moisture. Soil water pressure must be monitored three or four times a week for the TENS method, whereas monitoring soil WC for the CBWB can be performed once each 2 or 3 weeks. Water content data in the latter case serve primarily as checks to ensure the CBWB is predicting the actual field soil moisture conditions within satisfactory limits. The CBWB model can be reinitialized using these data, if necessary. Tensiometers must be installed at several representative sites throughout the field and serviced regularly. Whenever SWP decreases below a prespecified value, irrigation is required. On the other hand, several pieces of information must be collected daily in order to use the CBWB model. Daily rainfall, daily maximum and minimum temperature, and daily solar radiation are necessary inputs, and a 5-day weather forecast is needed.

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5. FLORENCE, SOUTH CAROLINA

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INTRODUCTION

Management practices to reduce the effects of drought in Coastal Plain soils are needed. Potential practices include the addition of water to the surface layer by irrigation, disruption of compacted soil layers by deep tillage to allow extraction of water stored in the subsoil, or a combination of irrigation and deep tillage. The most efficient and economical practice must be determined, since both deep tillage and irrigation require high energy inputs. Although conservation tillage is most often implemented to reduce soil loss, the practice also offers other advantages, including improved water infiltration and soil profile recharge, reduced evaporation, and improved water-use efficiency of stored water during short drought periods.

The objectives of this research were to determine the separate and collective effects of irrigation and tillage on corn grain yield and determine the optimum combination of irrigation and tillage for efficient corn production in Southeastern Coastal Plain soils.

METHODS

Corn (Zea mays L. cv. Pioneer 3369-A) was grown on an 18-ha site near Florence, SC, where the predominant soils are Bonneau loamy sand (Arenic Paleudult) and Norfolk loamy sand (Typic Paleudult). These soils had a compacted E horizon 20 to 60 mm thick at a depth of 0.20 to 0.30 m.

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Four irrigation treatments and five tillage treatments were included in the study during the 3-year period, 1979-81. In three of the treatments, irrigation was scheduled by different methods, and in one treatment no irrigation was applied (NI). The computer-based water-balance method (CBWB) of scheduling irrigation utilized a water balance procedure adapted to a microcomputer and utilized meteorological data inputs to estimate evapotranspiration. This procedure is described in detail in chapter 2. Allowable depletion and rooting depth are two inputs which the user must estimate. The allowable depletion for all 3 years of this study was 50%. In 1979, the rooting depth was assumed to be constant at 0.60 m. In the other 2 years, it was assumed to increase stepwise to a maximum of 0.71 m.

The screened pan evaporation (SPE) method of scheduling irrigation was based on potential evapotranspiration (Campbell and Phene 1976, Doty et al. 1982). Irrigation was initiated when the water level in a screened evaporation pan dropped to a preset level below the overflow. Rainfall in excess of the simulated soil storage was wasted via an overflow. Since several soil types were present in the irrigated area (table 1), the predominant soil with the smallest available water volume in the rooting zone (58 mm) was used to calculate the allowed depletion. The active rooting zone was estimated to be 0.75 m, and irrigation was to be applied when 50% of the available water in the rooting zone was depleted. Therefore, irrigation was applied when 29 mm (50% x 58 mm) of water had evaporated from the pan. This means that the soil with the largest available water volume (87 mm) was irrigated at a depletion of 39%. At irrigation, water in the evaporation pan was replenished by a volume corresponding to the effective irrigation depth applied by the irrigation system.

Table 1.
Location, by sector and soil type, for irrigation treatments during the 3-year study (1979-81)*

Irrigation treatment/location		Tillage treatment	Soils
			1979
CBWB	B	DDSS	NoA(40) BnB(60)**
		MTSS	NoA(50) BnB(50)
		CP	NoA(55) BnB(45)
		DD	NoA(50) BnB(50)
		MT	NoA(50) BnB(50)
SPE	D	DDSS	BnB(30) OcA(30) NoB(15) WgA(25)
		MTSS	BnB(30) OcA(30) NoB(15) WgA(25)
		CP	BnB(40) OcA(15) NoB(15) WgA(25)
		DD	BnB(40) OcA(20) NoB(15) WgA(25)
		MT	BnB(35) OcA(20) NoB(20) WgA(25)
TENS	C	DDSS	BnB(20) OcA(05) CxA(05) NoB(65) LyA(05)
		MTSS	BnB(20) OcA(05) CxA(20) NoB(50) LyA(05)
		CP	BnB(20) OcA(05) CxA(25) NoB(50)
		DD	BnB(20) OcA(05) CxA(05) NoB(50) LyA(20)
		MT	BnB(15) OcA(10) NoB(75)
NI	A	DDSS	NoA(45) BnB(30) OcA(20) RnA(05)
		MTSS	NoA(45) BnB(30) OcA(20) RnA(05)
		CP	NoA(40) GoA(05) BnB(30) CxA(25)
		DD	NoA(40) GoA(10) BnB(20) OcA(10) RnA(05) CxA(15)
		MT	NoA(50) GoA(05) BnB(20) OcA(20) RnA(05)
			1980
CBWB	E	DDSS	NoA(85) BnB(10) OcA(05)
		MTSS	NoA(80) BnB(20)
		CP	NoA(70) BnB(25) OcA(05)
		DD	NoA(65) BnB(35)
		MT	NoA(90) BnB(05) OcA(05)
SPE	G	DDSS	BnB(90) NoB(10)
		MTSS	NoA(05) BnB(85) NoB(10)
		CP	NoA(05) BnB(85) NoB(10)
		DD	NoA(65) BnB(35)
		MT	NoA(20) BnB(70) NoB(10)
TENS	F	DDSS	NoA(30) BnB(50) OcA(10) NoB(10)
		MTSS	NoA(25) BnB(50) OcA(15) NoB(10)
		CP	NoA(25) BnB(65) OcA(05) NoB(10)
		DD	NoA(20) BnB(55) OcA(15) NoB(10)
		MT	NoA(25) GoA(05) BnB(50) OcA(10) NoB(10)

See footnotes at end of table.

Table 1--Continued
Location, by sector and soil type, for irrigation treatments during the 3-year study (1979-81)*

Irrigation treatment/location		Tillage treatment	Soils
			1980 con.
NI	H	DDSS	NoA(30) BnB(65) BlA(05)
		MTSS	NoA(20) BnB(80)
		DP	BnB(100)
		DD	NoA(15) BnB(85)
		MT	NoA(10) BnB(90)
			1981
CBWB	C	DDSS	BnB(20) OcA(05) CxA(05) NoB(65) LyA(05)
		MTSS	BnB(20) OcA(05) CxA(20) NoB(50) LyA(05)
		CP	BnB(20) OcA(05) CxA(25) NoB(50)
		DD	BnB(20) OcA(05) CxA(05) NoB(50) LyA(20)
		MT	BnB(15) OcA(10) NoB(75)
SPE	B	DDSS	NoA(40) BnB(60)
		MTSS	NoA(50) BnB(50)
		CP	NoA(55) BnB(45)
		DD	NoA(50) BnB(50)
		MT	NoA(50) BnB(50)
TENS	D	DDSS	BnB(30) OcA(30) NoB(15) WgA(25)
		MTSS	BnB(30) OcA(30) NoB(15) WgA(25)
		CP	BnB(40) OcA(15) NoB(15) WgA(25)
		DD	BnB(40) OcA(20) NoB(15) WgA(25)
		MT	BnB(35) OcA(20) NoB(20) WgA(25)
NI	A	DDSS	NoA(45) BnB(30) OcA(20) RnA(05)
		MTSS	NoA(45) BnB(30) OcA(20) RnA(05)
		CP	NoA(40) GoA(05) BnB(30) CxA(25)
		DD	NoA(40) GoA(10) BnB(20) OcA(10) RnA(05) CxA(15)
		MT	NoA(50) GoA(05) BnB(20) OcA(20) RnA(05)

* Sectors are shown in figure 1 and relate to position within the center-pivot irrigation system.
**Soil and percentage contained in specified treatment:

NoA	Norfolk ls 0-2% slope	GoA	Goldsboro ls 0-2% slope
NoB	Norfolk ls 2-6% slope	LyA	Lynchburg sl 0.2% slope
BnB	Bonneau s 0-4% slope	OcA	Ocilla l 0-2 slope
BlA	Blanton s 0-2% slope	RnA	Rains sl 0-2% slope
CxA	Coxville sl 0-2% slope	WgA	Wagram s 0-2% slope

The third irrigation scheduling method used tensiometers (TENS). Irrigation was initiated when any two of six tensiometers in the 0.30- to 0.60-m-depth range reached a predetermined soil water pressure (SWP) value. This SWP value was -30 kPa in 1979 and -25 kPa in 1980 and 1981.

Five tillage treatments were included for both irrigated and nonirrigated treatments in a randomized complete block design with four replications. Tillage treatments were as follows:

DD	Double-disking, spring tooth harrowing with drag and planting.
DDSS	Double-disking, spring tooth harrowing with drag and in-row subsoiling at time of planting.
MT	Minimum tillage -- planting directly into residue without prior tillage.
MTSS	Minimum tillage with subsoiling -- planting directly into residue with in-row subsoiling but without prior tillage.
CP	Chisel plowing -- disking, chiseling, spring tooth harrowing with drag and planting.

Subsoiling (treatments DDSS and MTSS) was performed in the row only with a subsoiler-planter operated at its maximum depth (0.40 m). Chiseling (treatment CP) to a depth of about 0.35 m was accomplished using a chisel plow with tines spaced 0.25 m apart. All plots were planted using a six-row, in-row subsoiler-planter unit (Brown-Harden Super Seeder with John Deere-71 Flexi-planters). The subsoiler unit included a 50-mm-wide fluted (waffle) colter immediately in front of each subsoiler shank, which had a 65-mm-wide chisel point. A spider wheel tine was attached immediately behind the subsoiler shank to firm the soil for planting. Treatments that were not subsoiled (DD, MT, CP) were planted using the same equipment except that the subsoiler shanks were removed. Each tillage plot was 30 m long and six rows (5.8 m) wide.

Irrigated treatments were located within one quadrant of a high-pressure, center pivot irrigation system. Corn and soybean were grown in each of two quadrants of the center pivot system and were rotated between quadrants each year. The same tillage treatments were present in both corn and soybean and remained in the same location each year. Nonirrigated treatments (NI) were located immediately adjacent to the center pivot system (fig. 1). Three irrigation scheduling treatments were located in separate sectors within each quadrant. The location by sector for each of the irrigation scheduling treatments for each year of the study is shown in table 1. Soils within each plot are also shown in table 1. From these data it is apparent that there was considerable soil variation among and within treatments. Dates of selected crop management operations and crop development events for each year of the study are included in table 2.

Fertilizer was broadcast in 1979 and 1981 and applied in a band in 1980. Sidedress N was applied through the irrigation system for the irrigated treatments except in 1979, when it was broadcast in liquid form by ground equipment. Sidedress N for the NI treatment was broadcast every year as a liquid with ground equipment. The annual application of N, P, and K fertilizer was based on soil test recommendations and is reported in table 3. All treatments within a year received the same amount of fertilizer. Mean plant populations at harvest are also included in table 3. Pesticides were applied in accordance with South Carolina Cooperative Extension Service recommendations.

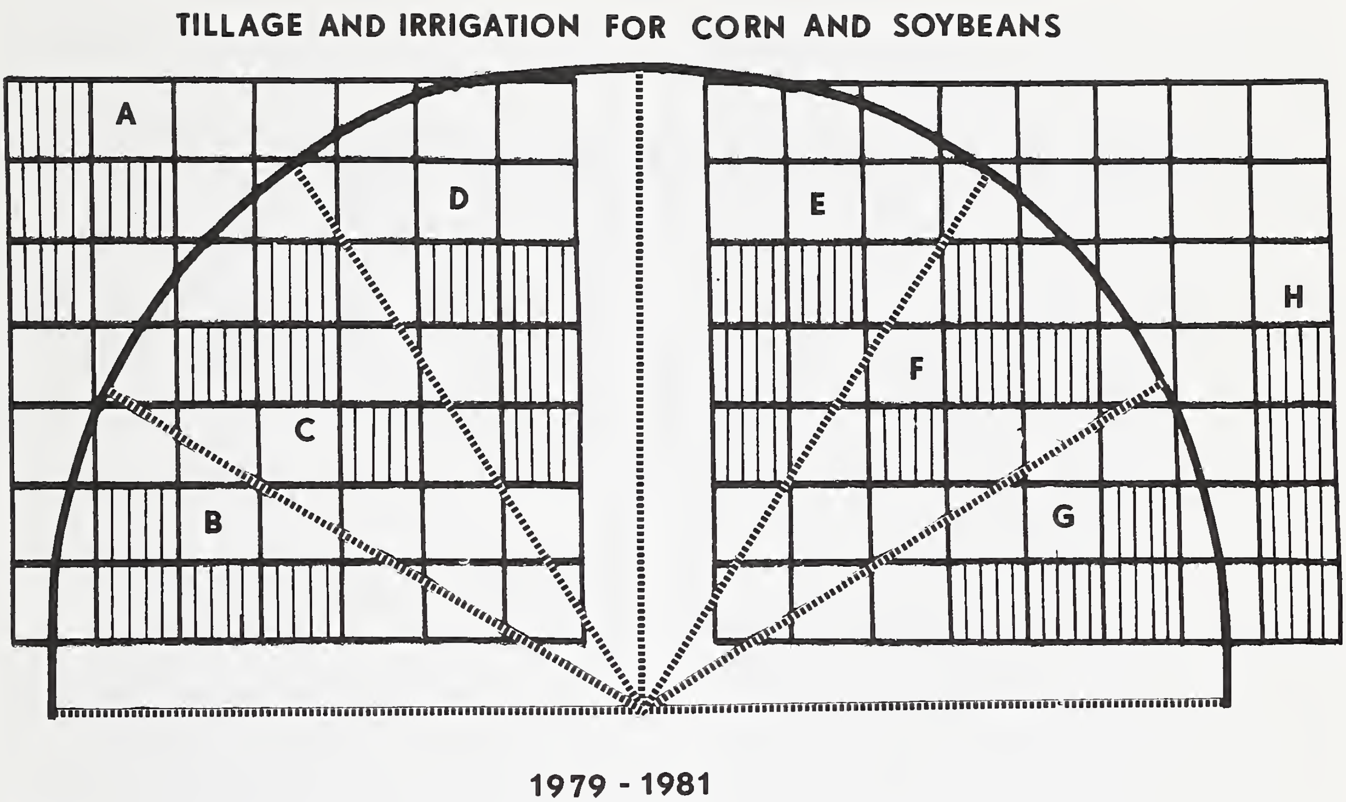

Figure 1.
Irrigation treatment areas (squares) are shown in sectors (B,C,D,E,F,G) of the center pivot system and could be irrigated independently. Nonirrigated treatment areas (A,H) are located outside the center pivot area. Tillage treatments are shown schematically as strips within the squares.

Table 2.
Dates of selected crop management operations and crop development events

Year	Dates			
	Planting	50% Emergence	Maturity	Harvest
1979	4 Apr	10 Apr	25 July	10 Sept
1980	25 Apr*	2 May	27 July	4 Sept
1981	30 Mar	7 Apr	27 July	24 Aug

*Second planting.

Table 3.
Plant population and fertilizer applied to corn during 1979-81 on Coastal Plain soils

Year	Plant Population		Fertilizer	
	Irrig.	Nonirrig.	Preplant(N-P-K)	Sidedress (N)
	----plants/ha----		----------kg/ha----------	
Corn				
1979	74,100	49,400	45-56-134	179
1980	66,700	45,200	34-67-201	34+132+67
1981	77,800	77,800	31-63-188	103+58+36

Tensiometers were installed at depths of 0.30, 0.45, and 0.60 m in the row of each tillage treatment in one randomly selected replication. Tensiometer measurements were recorded three times each week during the growing season. Rainfall and irrigation water applied were measured onsite, but other meteorological data required for the CBWB procedure were obtained at the Coastal Plains Soil and Water Conservation Research Center, which is located about 8 km from the site. Although a screen-covered, class A evaporation pan was used in the SPE irrigation scheduling treatment, daily measurements of evaporation were not obtained from this pan but from the Center's weather station. Irrigation was measured using a standard rain gauge located in the corn canopy under the center pivot system.

A 20-m segment of each of the four center rows of each plot was harvested using a two-row combine, and the samples were weighted for yield determination. All grain yields were corrected to 15.5% moisture. Corn grain yields were analyzed statistically using analysis of variance procedures and Duncan's multiple range test.

RESULTS AND DISCUSSION

Rainfall and irrigation received during the growing season for the 3 years (1979-81) of this study are shown in table 4 and figures 2, 3 and 4. Rainfall during the growing season in 1979 was adequate to satisfy evapotranspiration until early June, when irrigation was initiated. Although rainfall occurred intermittently, irrigation was required for the remainder of the growing season.

In 1980 rainfall during the growing season was much less, particularly during the vegetative stages, and irrigation was required every month of the growing season. The rainfall total for this growing season (227 mm) was the lowest in the 3 years. In 1981 rainfall was adequate during the early vegetative portion of the growing season but was deficient during the remainder of the growing season, so significant irrigation was required during June and July. This period of deficit rainfall occurred during pollination and grain fill, a very critical period for corn.

Table 4.
Irrigation and rainfall during the growing season for 1979-81

Irrigation treatment	Irrigation (mm) 1979	1980	1981	Mean
CBWB	121	333	213	222
SPE	192	297	177	222
TENS	158	325	269	238
Rainfall	427	227	365	340

Irrigation

In 1979 the SPE treatment required the greatest amount of irrigation (192 mm) while the CBWB treatment required the least amount (121 mm) (table 4). A major reason for the low irrigation requirement for the CBWB treatment was communication difficulties associated with the initiation of a new system. These difficulties caused delays in reporting data and in implementing irrigations. In 1980 the CBWB and TENS treatments required almost equal amounts of irrigation, while the SPE treatment required about 30 mm less water. This was the driest year of the study and resulted in fairly uniform irrigation intervals for all irrigation treatments. In 1981 the TENS treatment required the greatest amount of water for irrigation, and the SPE treatment required the least amount of water. Rainfall for this year was intermediate between the two previous years but was within 62 mm of the seasonal rainfall of the wettest year, 1979.

Irrigation water applied during the 3 years varied considerably, as did rainfall, but no one scheduling method consistently required the most water over the 3 years. When the mean irrigation amounts for the 3-year period are considered, the TENS treatment required more irrigation water than the other methods, but there was no difference between the other two methods.

There were some differences in soils for the irrigation treatments among the 3 years because the treatments were rotated among the six sectors of the center pivot system (table 1). Although the CBWB and SPE treatments were based on selected soil-water storage values that did not change as treatment location changed, the TENS treatment was subject to soil changes among years because tensiometers were located in the treatment areas and reflected their SWP. This could account for some of the variation in irrigation water required by the TENS treatment among the 3 years of the study.

Some variation in the irrigation water applied was due to the randomness of rainfall. For example, one method might require irrigation on a given day and another method might require irrigation the following 1 to 3 days, but rainfall after noon of the first day or the next day would preclude the need for irrigation the following days. This sequence of events occurred at least four times during the 3 years of the study but appeared to be random; nevertheless, SPE (three times) and CBWB (two times) treatments were affected more than the TENS treatment (once). Also, if more runoff should occur during high intensity storms than that estimated by the CBWB and SPE methods, these methods would overestimate the amount of stored soil water and would indicate the need for irrigation less frequently than the TENS treatment.

The water supply for the center pivot system failed about 29 June 1981. This resulted in reduced irrigation amounts for all treatments until 3 July, when rainfall replenished the water supply. Plant stress during this period was moderately high and probably reduced yield, but it was essentially equal among the three irrigation scheduling treatments.

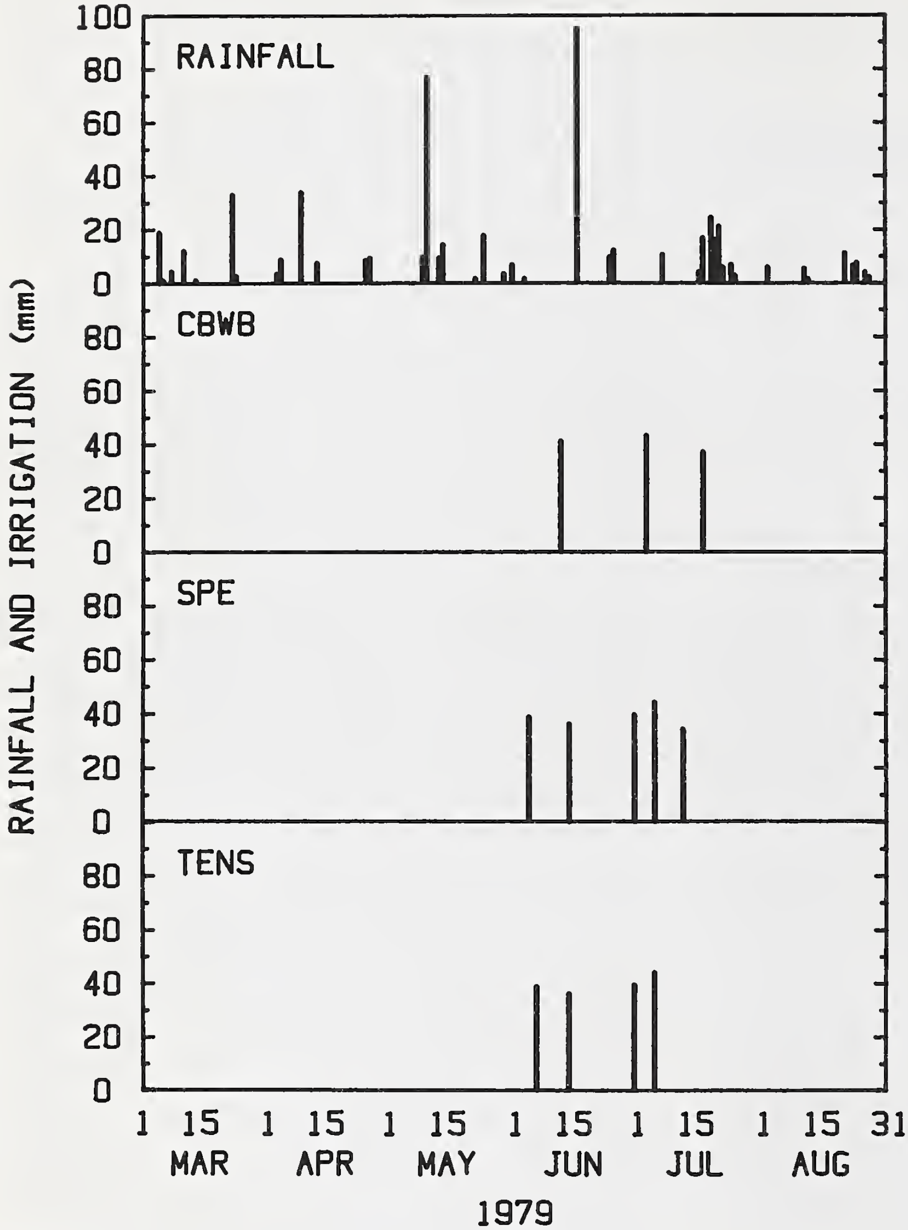

Figure 2.
Rainfall and irrigation applied to corn for three irrigation scheduling treatments in Florence, SC, during the growing seasons in 1979. CBWB = computer-based water balance; SPE = screened pan evaporation; TENS = tensiometer.

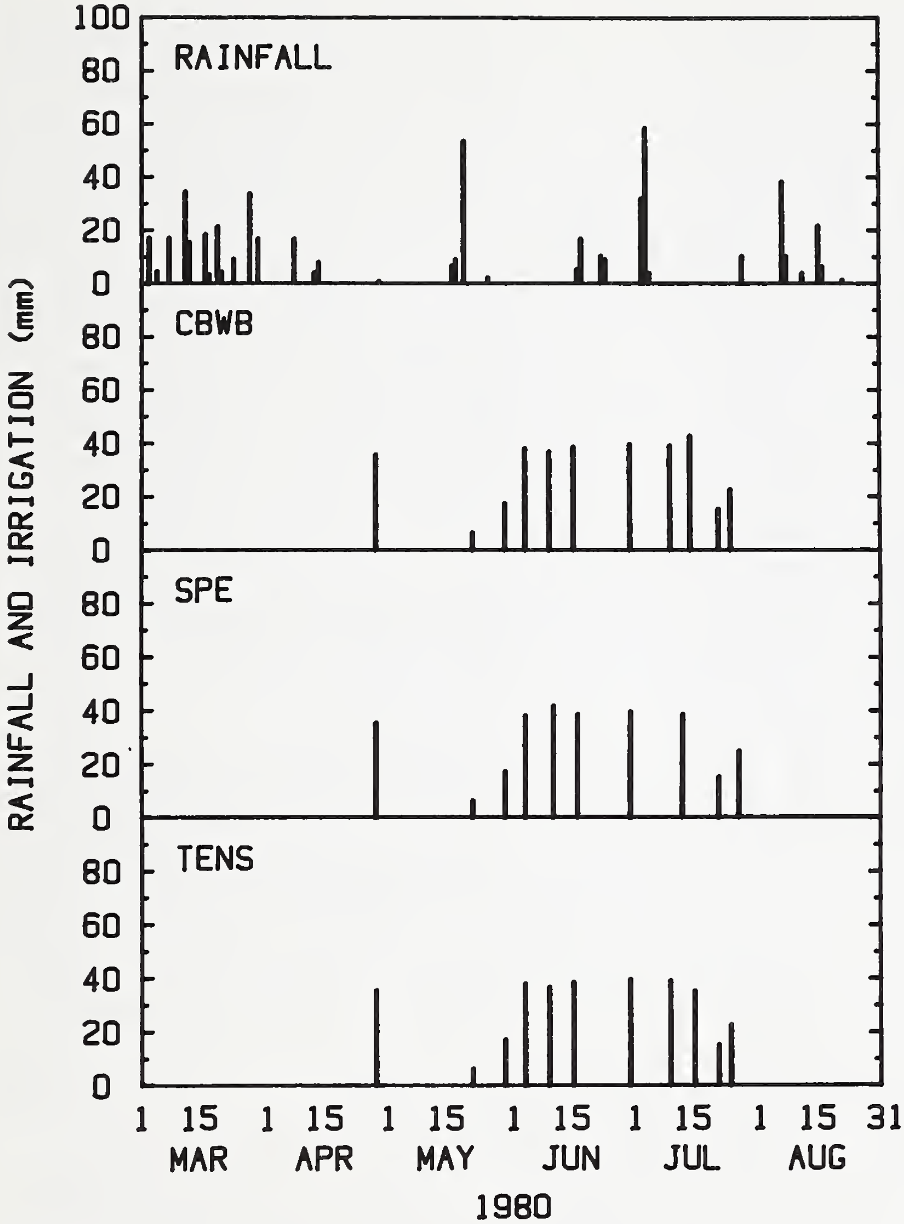

Figure 3.
Rainfall and irrigation applied to corn for three irrigation scheduling treatments in Florence, SC, during the growing season, 1980. CBWB = computer-based water balance; SPE = screened pan evaporation; TENS = tensiometer.

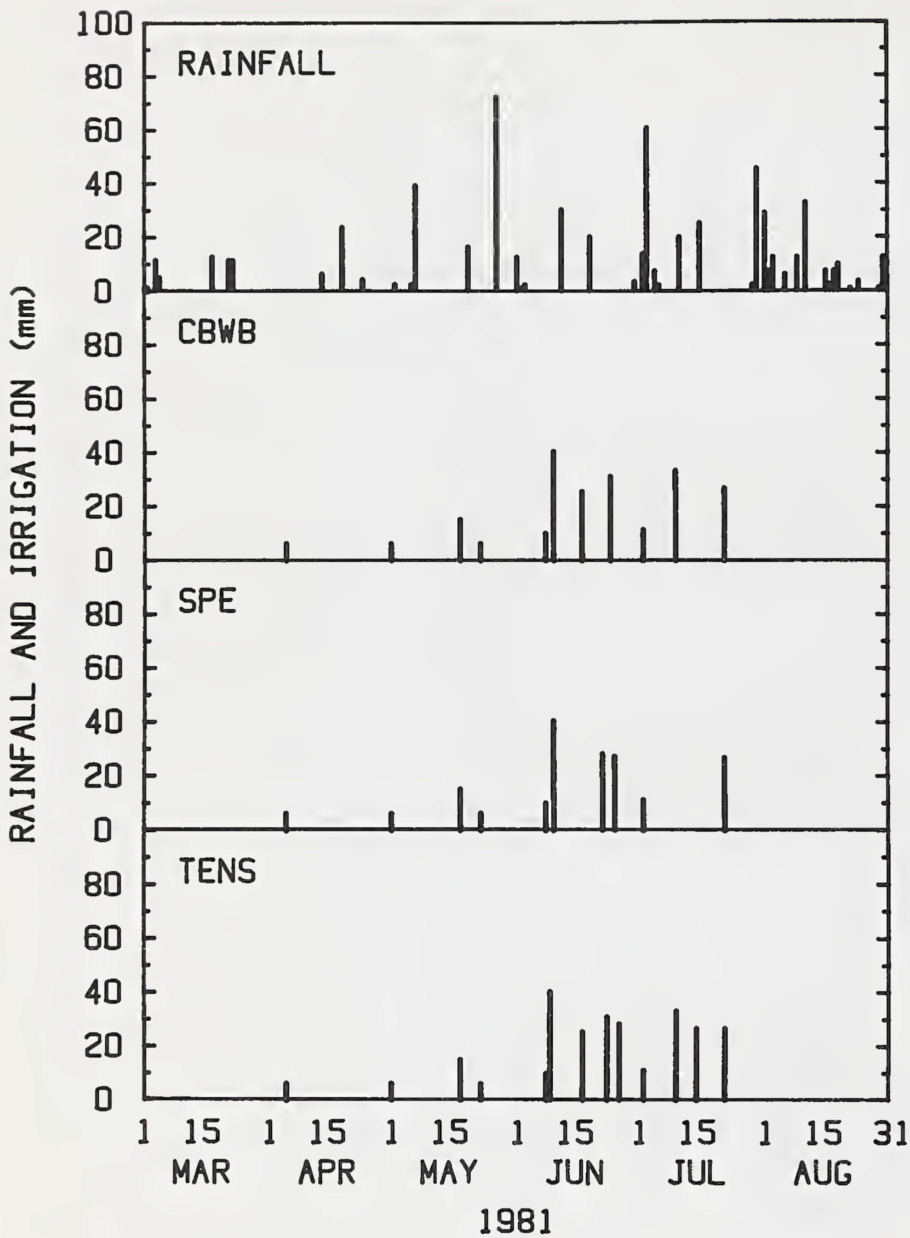

Figure 4.
Rainfall and irrigation applied to corn for three irrigation scheduling treatments in Florence, SC, during the growing season, 1981. CBWB = computer-based water balance; SPE = screened pan evaporation; TENS = tensiometer.

In 1979, corn grain yield was highest for the SPE treatment, which received the greatest amount of irrigation water (192 mm), but this yield was not significantly different from the yield for the TENS treatment, which received 158 mm of irrigation water (table 5). Additionally, the yield for the CBWB treatment was lowest of the three and received the lowest amount of irrigation water, but the yield was not significantly different from that of the TENS treatment. In 1980, corn grain yields were highest for the CBWB and TENS treatments, both of which received about 30 mm more irrigation water than the SPE treatment. In 1981 there was no statistical difference among the corn grain yields for all three irrigation scheduling treatments, although there was a maximum difference of 92 mm in irrigation water applied.

None of the three scheduling methods consistently produced the highest yield. Three-year mean grain yields were not statistically different. Although it appeared that corn grain yield was related to the amount of irrigation water applied in 1980, this was not the case in 1981. In that year, the greatest amount of water was applied in the TENS treatment, but the highest yield was produced in the CBWB treatment. From these data, it appears that factors other than irrigation and rainfall substantially affected the yields produced on these treatments.

The soil variation among the sectors of the center pivot system was probably the major factor contributing to this variance. Unfortunately, it was not possible to have multiple locations for the irrigation treatments because of

Table 5.
Mean corn grain yields for water management treatments in Coastal Plain soils for 1979-81

	Water management treatment*			
Year	CBWB**	SPE	TENS	NI
	---------------- Mg/ha ----------------			
1979	7.56 b***	9.67 a	8.94 ab	6.05 c
1980	6.69 a	4.83 b	6.28 a	2.25 c
1981	7.61 a	6.95 a	7.32 a	3.53 b
Mean	7.29 a	7.15 a	7.51 a	3.94 b

* Each yield value is mean of 5 tillage treatments.
** CBWB = Computer-based water balance; SPE = screened pan evaporation; TENS = tensiometer; NI = nonirrigated (rainfall only).
***Values followed by the same letter within a row are not statistically different at $P \leq .05$ according to Duncan's multiple range test.

operational restrictions of the center pivot system and the large land area required. Although the four blocks within a sector provided spatial replication, soil variation, in some cases, was greater among sectors than it was within a sector.

Mean corn grain yields across all tillage treatments were consistently higher for the irrigated treatments than for the NI treatment (table 6). This was true for all 3 years, but the difference between irrigated and NI yields was greatest in 1980 and 1981, the 2 years when rainfall during the growing season was lowest. Yield increases due to irrigation were similar for all tillage treatments, with mean increases of 3.80 Mg/ha for the subsoiled treatments, 3.05 Mg/ha for the CP treatment, and 3.10 Mg/ha for the nonsubsoiled treatments. The overall mean corn yield for irrigated treatments was 3.37 Mg/ha (86%) higher than that for the NI treatment.

Irrigation, rainfall, upper and lower limits of available soil water, critical level (CL), and daily soil-water content (SWC) as calculated by the CBWB procedure for both the CBWB and NI treatments and for all 3 years of the study are shown in figures 5-7. The soil-water volume available for plants is a function of rooting depth; therefore, this volume increases with time from planting until it reaches a maximum for the season. The CBWB procedure was operated in a batch mode, with no reinitialization to generate these graphs. Therefore, daily SWC values do not necessarily represent the values used in actually managing irrigation for the CBWB treatment on a real time basis.

As mentioned earlier, communication problems in 1979 caused some difficulty in the timely application of irrigation to this treatment. Notwithstanding the problems associated with this irrigation management program in 1979, corn grain yields for irrigated treatments were higher for this year than for any other year of the study. In 1980, temporary periods of soil saturation caused by overirrigation or by rainfall following soon after irrigation probably occurred and caused a measured potassium deficiency in corn plants. This deficiency resulted in excessive lodging and may have reduced yields. The existence of more periods of drought stress in 1980 and 1981 reduced corn yields on NI treatments and appeared to have reduced

Table 6.
Comparison of grain yields for irrigated and nonirrigated treatments in an experiment which included 5 tillage treatments in Coastal Plain soils

Year	Nonirrigated	Irrigated*	Increase
	---------Mg/ha---------		%
1979	6.05	8.72	44
1980	2.25	5.93	164
1981	3.53	7.29	107
Mean	3.94	7.31	86

* Mean of 3 irrigation treatments.

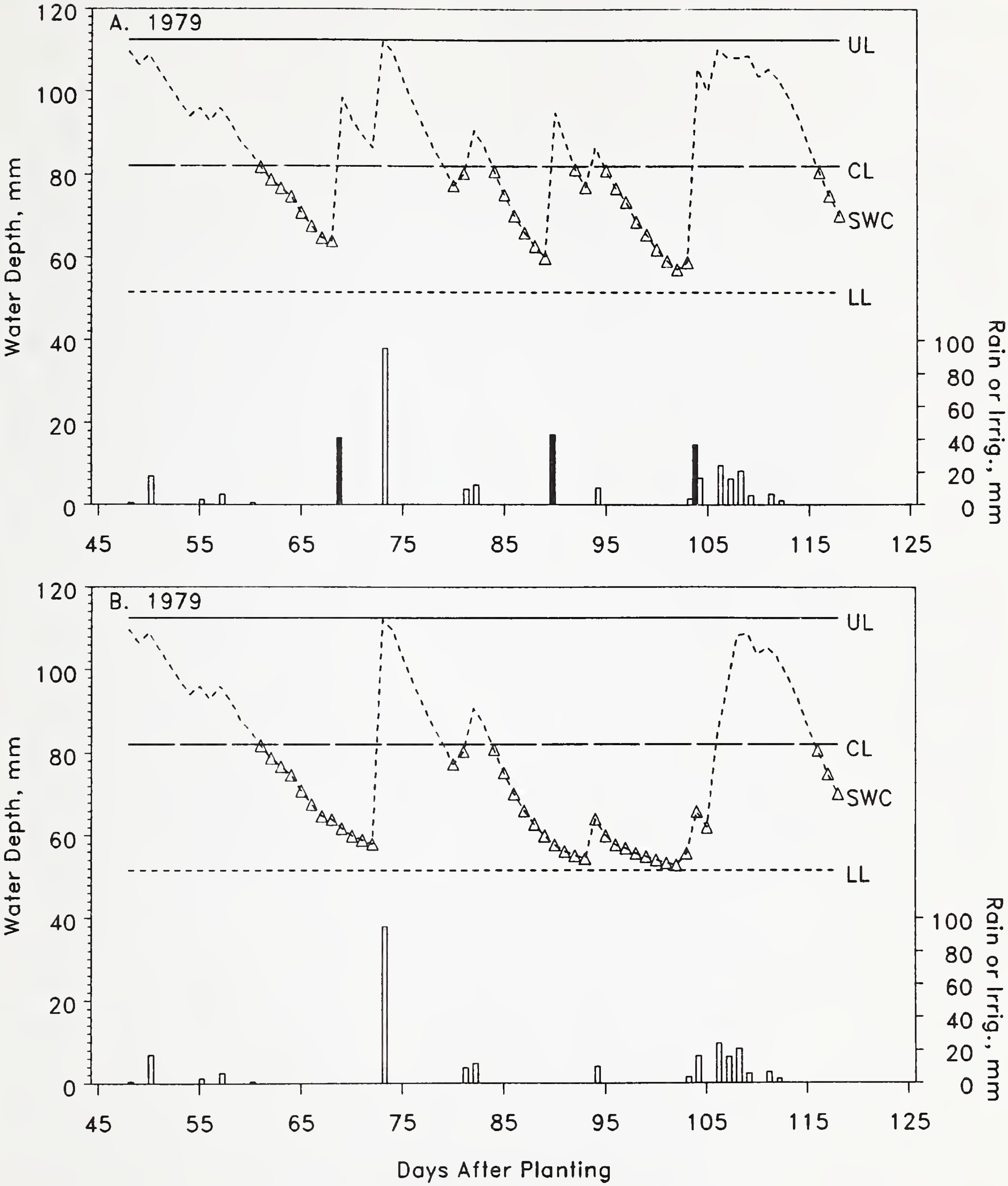

Figure 5.
Daily root-zone water content, irrigation, and rainfall data for (A) CBWB treatment and (B) NI treatment at Florence in 1979. Curves show the simulated water content (SWC) and the upper limit (UL), critical level (CL), and lower limit (LL) of available water; solid and open bars, respectively, show the amounts of irrigation (Irrig) or rain received: and triangles flag days when CBWB indicated the need for irrigation. Scale for bars shown on right vertical axis.

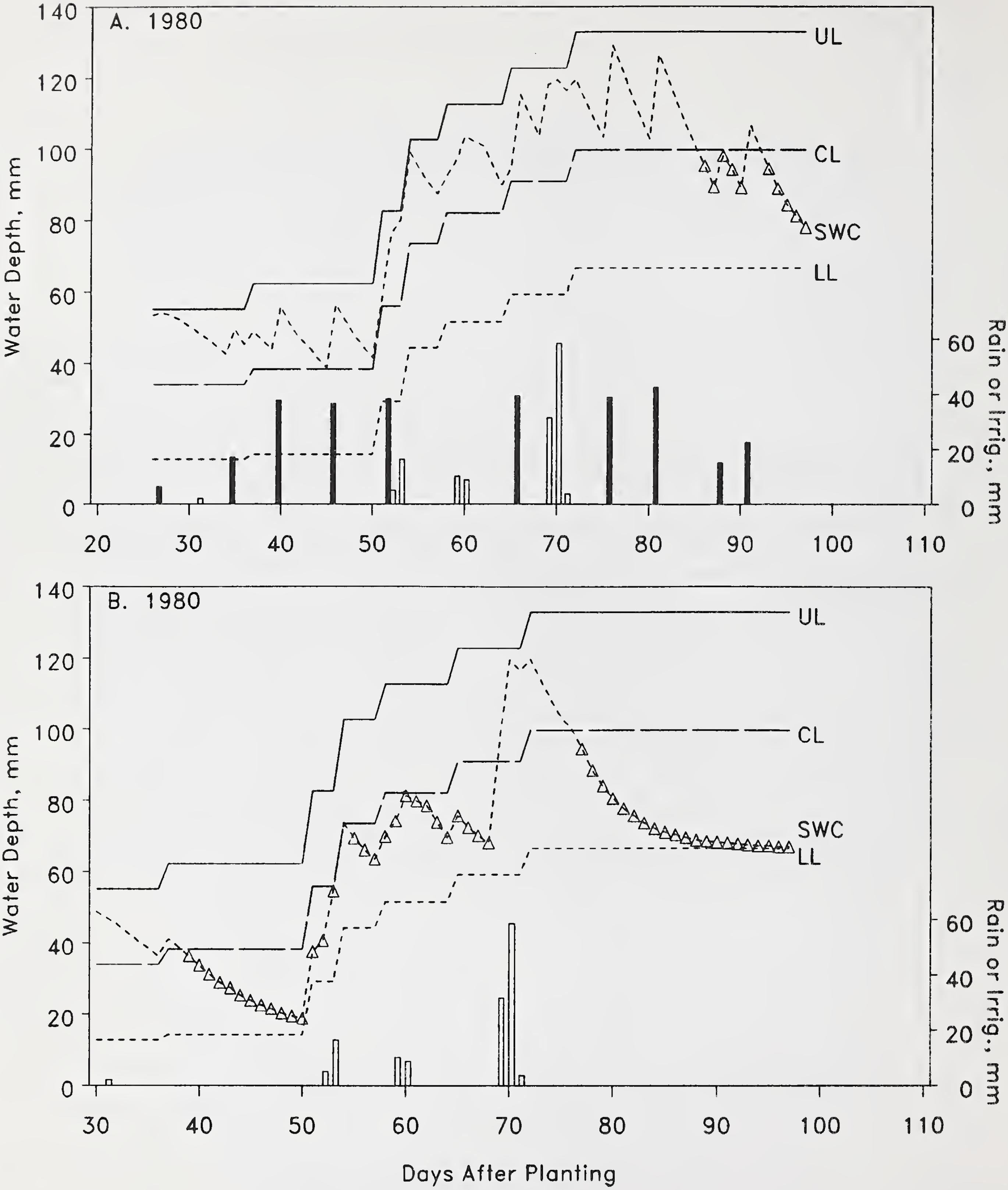

Figure 6.
Daily root-zone water content, irrigation, and rainfall data for (A) CBWB treatment and (B) NI treatment at Florence in 1980. See figure 5 legend for explanation of symbols.

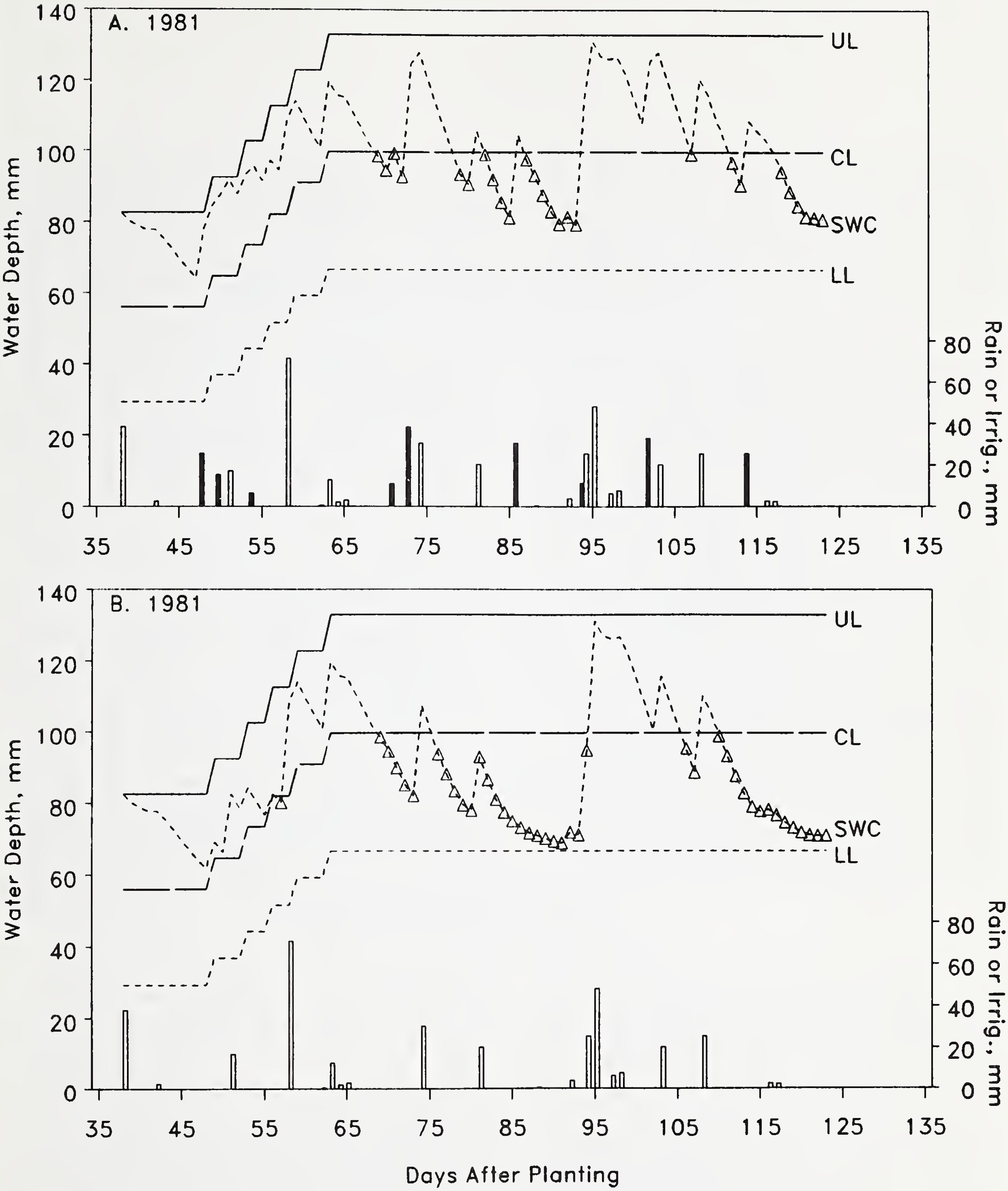

Figure 7.
Daily root-zone water content, irrigation, and rainfall data for (A) CBWB treatment and (B) NI treatment at Florence in 1981. See figure 5 legend for explanation of symbols.

yields on irrigated treatments. This indicates that irrigation management was not precisely matched with need or was not executed as specified. Water supply problems in 1981 prevented the timely application of irrigation, particularly during the period 29 June-3 July (91-95 days from planting).

Soil water pressure data as determined by tensiometers could not be used to accurately estimate volumetric soil-water content because of soil variation within and among treatments; therefore, simulated and measured soil water contents could not be compared. Also, tensiometer data were not sufficient in scope and number to accurately estimate water loss via deep percolation; however, losses of this type probably occurred, particularly during periods of high soil water content.

Potential evapotranspiration (PET) and actual evapotranspiration (AET) values calculated by the CBWB procedure for equal time periods (22 May-31 July) were 404 and 322 mm in 1979, 453 and 307 mm in 1980, and 446 and 348 mm in 1981. AET values calculated by the CBWB procedure for NI treatments were 231, 164, and 275 mm for the same time periods.

Tillage

Mean corn grain yields for the deep tillage (DDSS, MTSS, CP) treatments were significantly higher than those for the other tillage treatments during the 3 years of this study for both irrigated and NI conditions (table 7). Subsoiled treatments (DDSS, MTSS) produced the highest yields, and the nonsubsoiled treatments (DD, MT) produced the lowest yields. There were no significant differences in yield between the two subsoiled tillage treatments (DDSS, MTSS). Tensiometer data showed that water was extracted at the 0.60-m depth on a deep tillage treatment but not in shallow tillage treatments, indicating that rooting was deeper in this treatment. Root observations in pits excavated near the end of the 1979 season also indicated rooting was deeper in the deep tillage treatments (0.40-0.45 m) than in shallow tillage treatments (0.18-0.20 m).

The magnitude of yield differences among tillage treatments varied with year and with irrigation treatment, but the yield rankings of tillage treatments were consistent across time and irrigation treatment with few exceptions. Based on the 3-year means for the irrigated treatments, subsoiling increased corn grain yield 2.21 Mg/ha for the DD treatment and 2.81 Mg/ha for the MT treatment, while CP increased yields 0.89 Mg/ha when compared with the DD treatment (table 7). Without irrigation the yield increases were 1.73, 1.91, and 1.25 Mg/ha, respectively, for the same comparisons. In both cases, the greatest yield increase due to subsoiling was produced on the minimum tillage treatment. This may have been partly due to the consistently low yield for the MT treatment. Although no measurements were made, observations indicated that plant emergence and seedling growth and vigor were poorer and weed competition caused by lack of canopy shading was greater for the MT treatment than for the other tillage treatments.

With irrigation, deep tillage further increased corn yield over the shallow tillage treatments. For example, a 3-year mean corn yield increase of 2.21 Mg/ha was obtained with subsoiling for the DD treatment with irrigation. The yield increase due to subsoiling for the same treatment without irrigation was 1.73 Mg/ha. The yield increase due to irrigation was 3.41 and 3.89 Mg/ha for the DD and DDSS treatments, respectively. Therefore, both subsoiling and irrigation increased corn yields, and the benefits of these two practices appear to be additive for these soils. This probably is because of better nutrient recovery from

Table 7.
Mean corn grain yields for 5 tillage treatments, both with and without irrigation, on Coastal Plain soils for 1979-81

Year	Tillage treatment				
	DDSS*	MTSS	CP	DD	MT
	Mg/ha				
			Irrigated**		
1979	9.81 a***	9.33 ab	9.00 ab	8.24 bc	7.24 c
1980	7.18 a	7.33 a	5.56 b	4.45 b	5.12 b
1981	9.04 a	8.67 a	7.52 b	6.72 c	4.51 d
Mean	8.68 a	8.44 ab	7.36 bc	6.47 cd	5.63 d
			Nonirrigated		
1979	6.47 a	6.82 a	6.74 a	5.27 a	4.95 a
1980	2.99 a	3.06 a	2.03 ab	1.44 b	1.72 b
1981	4.90 a	4.31 ab	4.17 ab	2.47 bc	1.79 c
Mean	4.79 a	4.73 a	4.31 a	3.06 b	2.82 b

* DDSS = double disking and in-row subsoiling; MTSS = minimum tillage and in-row subsoiling; CP = chisel plowing; DD = double disking; and MT = minimum tillage.
** Means of three irrigation scheduling treatments.
***Values followed by the same letter within a row are not statistically different at $P \leq .05$ according to Duncan's multiple range test.

the deeper soil layers by deeper penetrating roots in the deep tillage treatments.

In these soils, N and K are very mobile and, following rainfall, easily leach from the surface soil layer to the subsoil, where they may be unavailable to plants with restricted root systems. Leaching is especially likely when rainfall occurs shortly after irrigation or a previous rainfall, when the upper soil profile is very wet. On the other hand, if plant roots were restricted to a soil depth shallower than that used to estimate soil water storage or to schedule irrigation, plant water stress may have become high enough to reduce yield even under irrigation. In this case, the soil-water regime in the deep tillage treatments would have been more nearly optimal than that in the shallow tillage treatment; but no observations, including SWP measurements, indicated that this was the case. Langdale et al. (1981) suggested that water and nutrient recovery from the deeper depths of a similar

Coastal Plain soil was responsible for increased corn grain yield and better N utilization on subsoiled treatments under irrigated conditions.

CONCLUSIONS

Irrigation water required by the three irrigation scheduling treatments varied considerably for the 3-year study, but no method consistently required the highest or lowest amounts of water. Some of the differences in the amounts of irrigation water applied were due to the random occurrence of rainfall; that is, there was usually 1 to 3 days' difference in the time irrigation was scheduled by the three methods, and rainfall often occurred during that interval. This removed the need to irrigate those treatments scheduled for the later part of the interval. The 3-year mean irrigation totals were very similar among the three scheduling methods.

Likewise, there were no significant differences in the 3-year mean corn grain yields among the three methods. There were significant differences in yield among the irrigation scheduling treatments in 1979 and 1980; but, again, no method consistently produced the highest or lowest yields. Therefore, until refinements are made in these methods of scheduling irrigation, the farmer should choose the method best suited to his/her needs.

Deep tillage increased corn grain yields for both irrigated and NI conditions over the 3-year period, but the yield increase was greater with irrigation than without. The yield increase due to irrigation was similar for all tillage treatments, and the mean yield was 86% higher with irrigation.

Deep tillage and irrigation produced an additive increase in corn grain yield. The yield increase due to deep tillage without irrigation was 1.74 Mg/ha while the yield increase due to the combined effects of irrigation and deep tillage was 5.62 Mg/ha. Consequently, where root restrictions occur in these layered soils, it may be profitable to both subsoil and irrigate.

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6. BLACKVILLE, SOUTH CAROLINA

V.L. Quisenberry[1]

INTRODUCTION

Many soils in the Coastal Plains region of South Carolina contain compacted zones which greatly influence crop root growth as well as water, air, and solute movement (Campbell et al. 1974). Some form of deep tillage, usually in-row subsoiling, has become an accepted farm practice to reduce the detrimental effects of compaction. In general, yield increases have been significant for corn, cotton, and soybean (Suman and Peele 1974, 1976)

With the increase in irrigation in South Carolina during the last decade, agronomists have been required to evaluate cropping recommendations for irrigated conditions. One of the basic questions has been, Is in-row subsoiling necessary with irrigation? Quisenberry and Musen (1983) reported that in-row subsoiling did not increase soybean yields over those of disked fields when irrigation was applied. Because corn differs from soybeans in growth pattern both below and above ground, the same type of information must be obtained for corn.

A tillage-irrigation study was conducted on a compacted Coastal Plain soil for 3 years to meet the following objectives:

1. To characterize those hydraulic properties of a Wagram sand which influence irrigation management.
2. To determine the effects of in-row subsoiling on corn yield under different irrigation management systems.
3. To compare different irrigation scheduling methods.

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MATERIALS AND METHODS

Experiments were conducted to measure the hydraulic properties of a Wagram sand and to apply these data in measuring evapotranspiration and soil water extraction patterns of a corn crop for different tillage and irrigation conditions.

Soil Physical Properties

In situ hydraulic conductivity and associated properties were determined at three sites in a 2.0-ha field at the Edisto Experiment Station near Blackville, SC. The field had been in a soybean and corn rotation for several years.

Each in situ plot was prepared by leveling and enclosing an area 4 m by 4 m with boards. The boards were installed in narrow trenches to a depth of 0.18 m, and the soil was thoroughly compacted around the boards to reduce seepage of water. Tensiometers with mercury manometers were placed in triplicate in each plot at depths of 0.08, 0.15, 0.23, 0.30, 0.46, 0.61, 0.76, 0.91, 1.22, and 1.52 m. Water was ponded on the soil surface until no significant change in soil water pressure (SWP) with time was observed for each depth. The plot was covered with plastic for the first 13 days of the run and then uncovered for another 37 days to permit evaporation.

The soil water content at each depth was estimated from the tensiometer data and soil-water desorption curves. At the conclusion of the evaporation period, three undisturbed cores were removed from each plot at depths corresponding to the depths of the tensiometers. Bulk density determination and textural analyses were made from these cores following the desorption runs.

Irrigation Experiments

The experiments were composed of four irrigation treatments and two tillage treatments arranged in a randomized complete block design with four replications. The four irrigation treatments were (1) no irrigation, (2) irrigation when the SWP decreased to -20 kPa at the 0.15- and 0.30-m depths for disked and subsoiled treatments, respectively, (3) irrigation when the SWP at the above depths reached -100 kPa, and (4) irrigation according to a computer-based water balance (CBWB) model. The two tillage treatments were in-row subsoiling to a depth of approximately 0.38 m and disking alone.

Corn (cv. Pioneer 3369A) was planted in late March or early April in 1979-1981. Plots were fertilized according to soil test recommendations for P, K, S, and lime. Nitrogen was provided at the rate of 224 kg/ha in two applications. Recommended weed control procedures were followed.

Evapotranspiration rates for short periods were calculated by determining the water lost as measured by the tensiometer readings and relating the SWP to water content by the desorption curves. Soil water extraction was calculated for zones in the profile by determining the change in water content across that zone and correcting for soil water flux into or out of the zone from the hydraulic conductivity and hydraulic gradient.

In 1980, root measurements were made four times during the growing season on selected plots. Cores (152 mm long and 20 mm in diameter) were taken at several depths and locations perpendicular to the row. The soil cores were washed, and root length was estimated by the method of Newman (1966).

RESULTS AND DISCUSSION

Soil Physical Properties

The soil at the experimental site was mapped as a Wagram sand. This soil typically has a sand or loamy sand texture extending from a depth of 0.5 to 1.0 m. The particle size distribution through 1.5 m of the Wagram sand at the experimental site is presented in table 1. The upper 0.6 m of this soil is composed of sand and loamy sand textures, with much of the sand falling into the medium and coarse ranges. The entire experimental area was mapped for depth to clay on an 8-m grid. Depth to the argillic horizon ranged from 0.44 to 0.98 m, but the depth to clay in approximately 80% of the area was between 0.65 and 0.76 m.

Soil bulk densities were greater than 1.78 Mg/m^3 throughout the Ap and E horizons. Bulk densities of this magnitude are common in many Coastal Plain soils. A compacted zone, which was observed from about 0.07 to 0.20 m, was probably a traffic pan. However, bulk densities in the lower portion of the E horizon were as high as those measured in the traffic pan. In-row subsoiling to a depth of 0.38-0.40 m could not establish a disrupted zone throughout the entire zone of high bulk density.

Soil water desorption curves for selected depths are shown in figure 1. While water contents varied among horizons for a given SWP, the general water-content/water-pressure relationships were quite similar. At all depths, the soil water content decreased rapidly as the SWP decreased from 0 to about -20 kPa. Little additional decrease in water content was measured as SWP further decreased to -100 kPa.

Table 1.
Particle size distribution and bulk density of selected depths of Wagram sand

Depth	Sand*						Silt	Clay	Texture**	Bulk Density
	vc	c	m	f	vf	total				
m	----------------			%		----------------				Mg/m^3
0.15	7	35	28	15	3	88	8	4	s	1.85
0.30	11	36	30	11	1	89	7	5	ls	1.78
0.45	6	30	26	17	5	84	12	4	ls	1.84
0.60	4	21	33	12	4	85	19	4	ls	1.80
0.90	1	18	27	12	2	64	22	17	sl	1.62
1.20	4	20	27	12	2	64	12	24	scl	1.55
1.50	3	12	29	13	3	60	13	27	scl	1.51

* vc = very coarse, c = coarse, m = medium, f = fine, vf = very fine.
**s = sand, ls = loamy sand, sl=sandy loam, scl = sandy clay loam.

Soil water pressure was measured as a function of depth at selected times during a 20-day period of drainage after the soil had been thoroughly wetted and then covered (fig. 2). Soil water pressures decreased rapidly during the early stages of drainage with values varying between -3 and -4 kPa in the upper 0.6 m at the end of day 1. On day 20, SWP in the surface 0.6 m (Ap and E horizons) ranged from a low of -6.5 kPa at the 0.08-m depth to -4.1 kPa at the 0.45-m depth. A much lower SWP was measured in the argillic horizons: -9 kPa at the 0.76-m depth. Numerous drainage experiments on Norfolk and Dothan soils showed similar drainage patterns. The SWP was much less in the upper portion of the Bt horizon than in the lower portion of the E horizon after an extended period of drainage. This can significantly influence the total amount of soil water lost due to evaporation.

The same plots used for the covered drainage experiment were rewetted and allowed to drain while the surface was exposed to permit evaporation. After 17 days of evaporation, the SWP was still no lower than -12.3 kPa at the 0.08-m depth. The SWP indicates that the flux was in the upward direction above the 0.45-m depth (fig. 3). Experiments showed that the SWP in the upper segment of the Bt horizon decreased faster by drainage than the SWP in the lower E decreased by drainage and/or evaporation (Unpublished data). Therefore, an upward flux could not develop across the E-Bt interface.

Hydraulic conductivity (K) decreased quite rapidly with decreasing SWP at all depths (fig. 4). As SWP decreased below -5 kPa, K was less than 10 cm/day within the Ap and E horizons. Rainfall and irrigation amounts for all irrigation and tillage treatments are included in table 2.

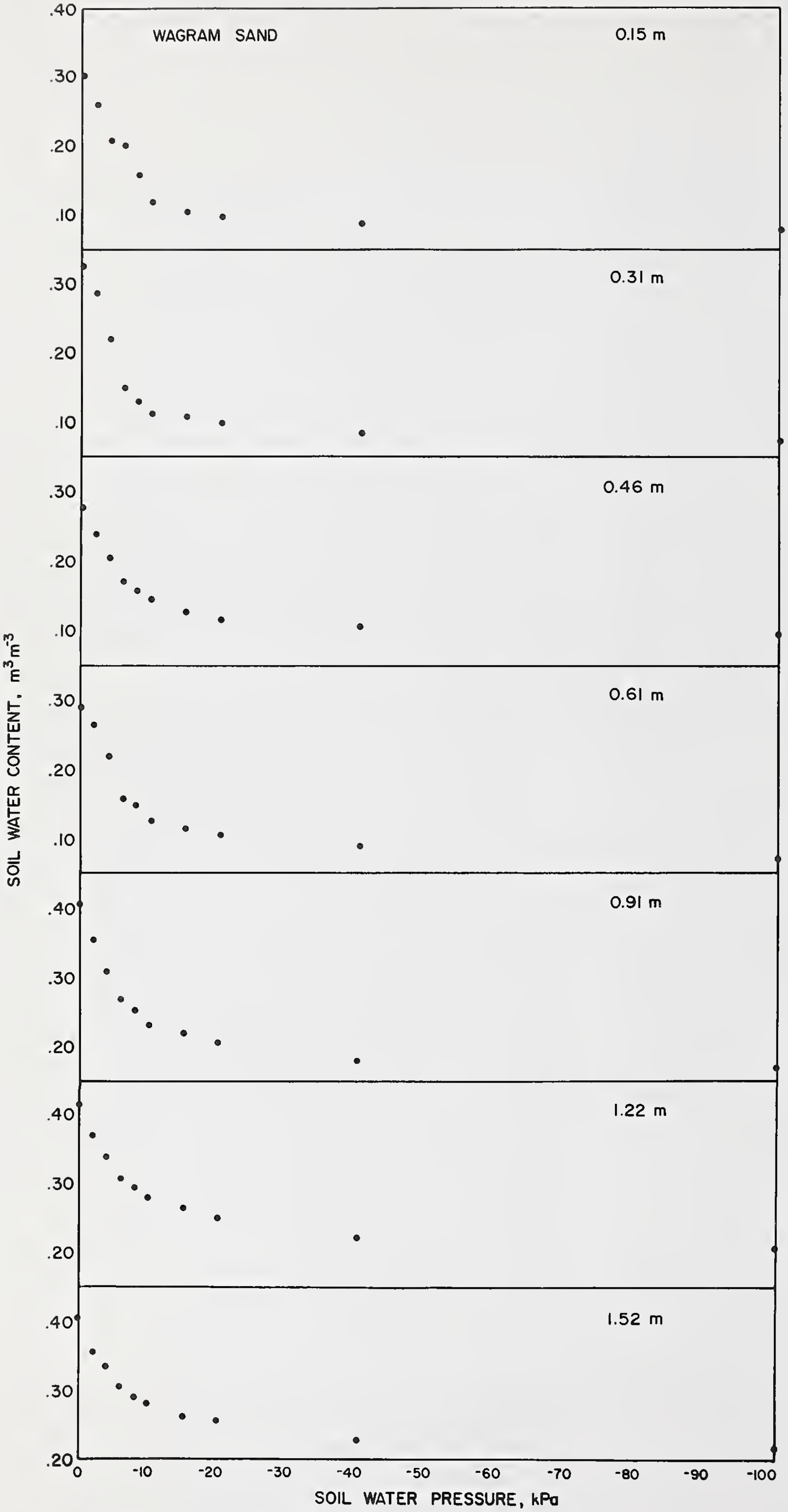

Figure 1.
Soil water desorption curves for selected depths of Wagram sand.

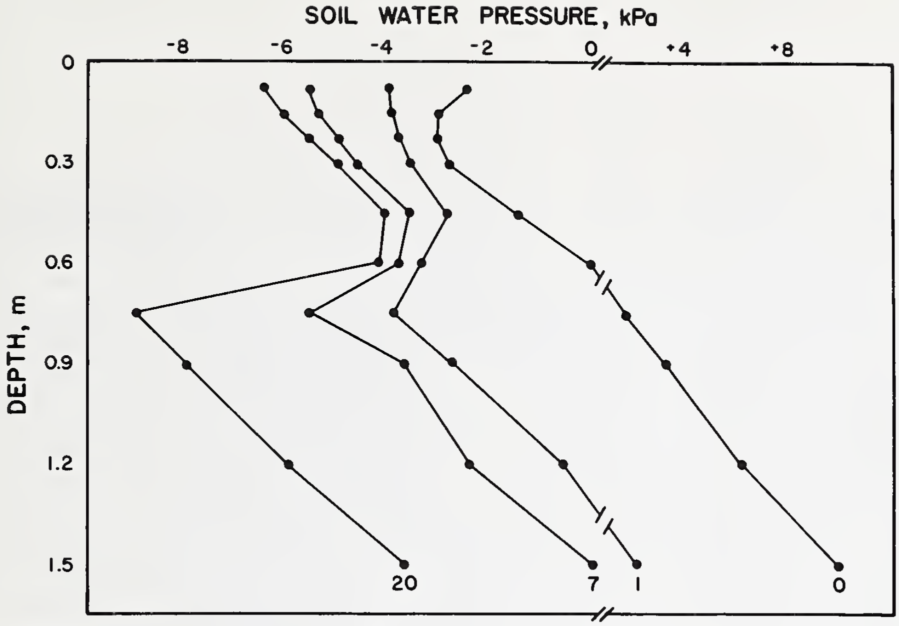

Figure 2.
Soil water pressure as a function of time and depth during a drainage period with the surface covered to prevent evaporation. Numbers on curves indicate drainage time in days.

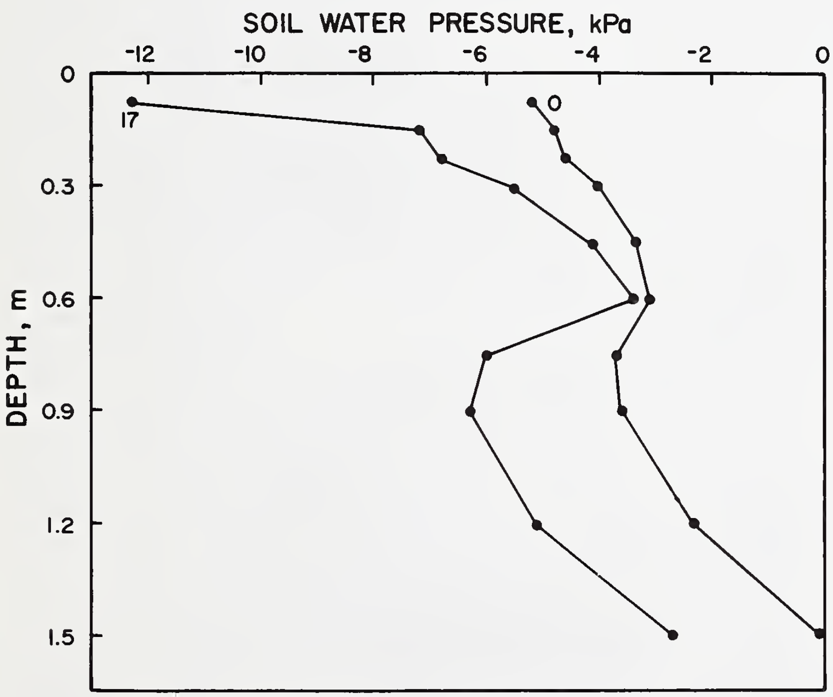

Figure 3.
Change in soil water pressure as a function of depth during a 17-day evaporation period.

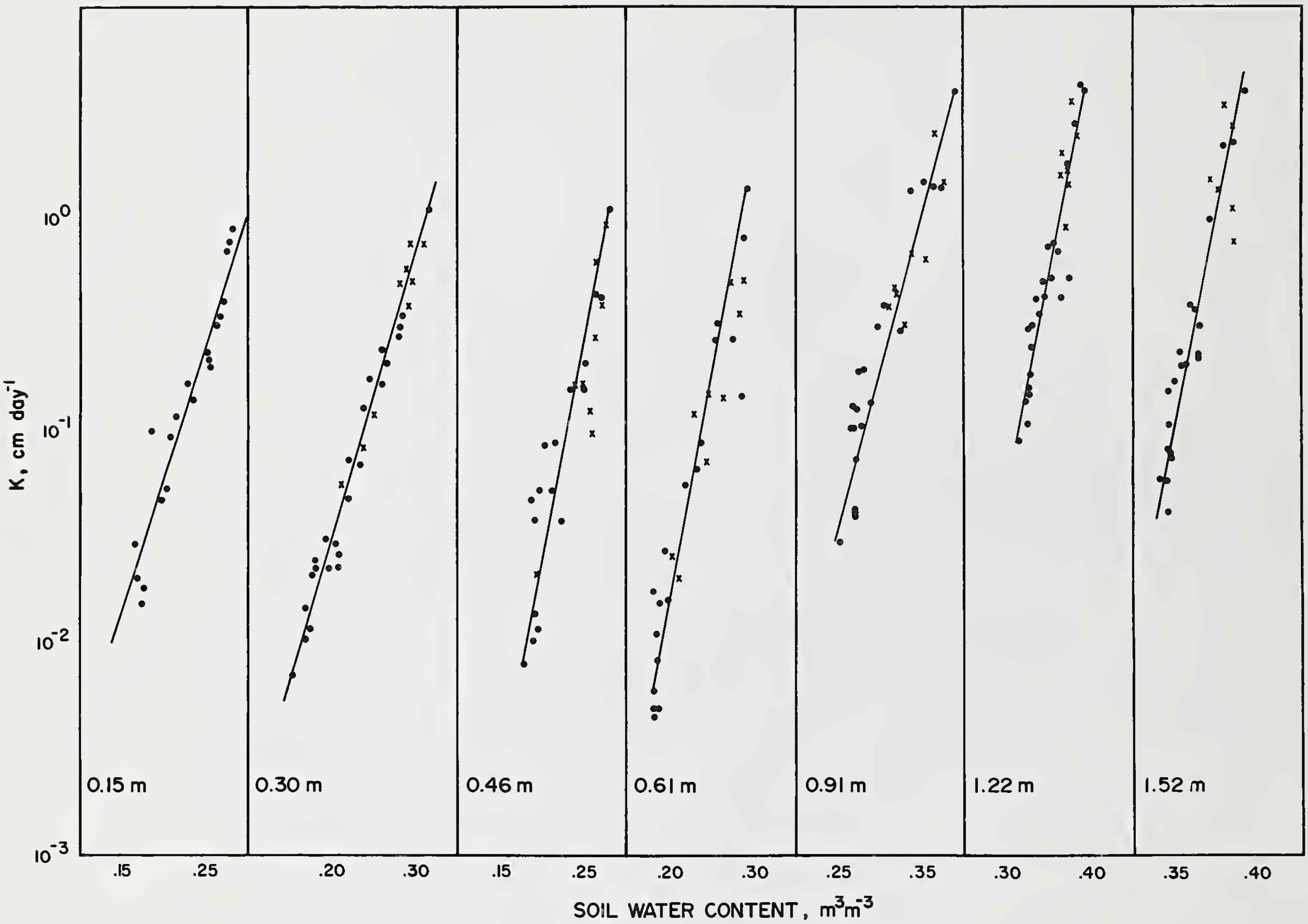

Figure 4.
Hydraulic conductivity (K) as a function of soil water content for selected depths.

Table 2.
Rainfall and irrigation amounts for each irrigation and tillage treatment on Wagram sand

Year	Rainfall(mm)	Tillage	Irrigation(mm)		
			-20kPa	-100kPa	CBWB
1979	246	Disked	76	43	150
		Subsoiled	64	81	75
1980	247	Disked	311	332	369
		Subsoiled	342	300	215
1981	325	Subsoiled	226	152	150

Soil-Strength/Soil-Water-Content Relationships

Numerous experiments have shown that root growth is greatly reduced or stopped if soil strength exceeds 2000 kPa as measured by a penetrometer. Soil strength was measured as a function of water content for the Ap and E horizons. Following disking, the bulk densities of the Ap and E horizons were 1.85 and 1.81 Mg/m^3, respectively (fig. 5). At soil water contents above 0.15 m^3/m^3, soil strength was less than 1000 kPa in both horizons. As the water content decreased below 0.15 m^3/m^3, soil strength increased rapidly, rising above 2000 kPa at water contents of approximately 0.10 m^3/m^3. The SWPs were only -14.0 kPa and -12.0 kPa for the Ap and E horizons, respectively, when soil strength reached 2000 kPa. Following subsoiling (23 days), the bulk density was reduced to about 1.5 Mg/m^3 in both horizons, and the water content which corresponded to 2000 kPa soil strength was reduced to 0.07 m^3/m^3 (-150 kPa SWP) and 0.06 m^3/m^3 (-150 kPa) for the Ap and E horizons, respectively.

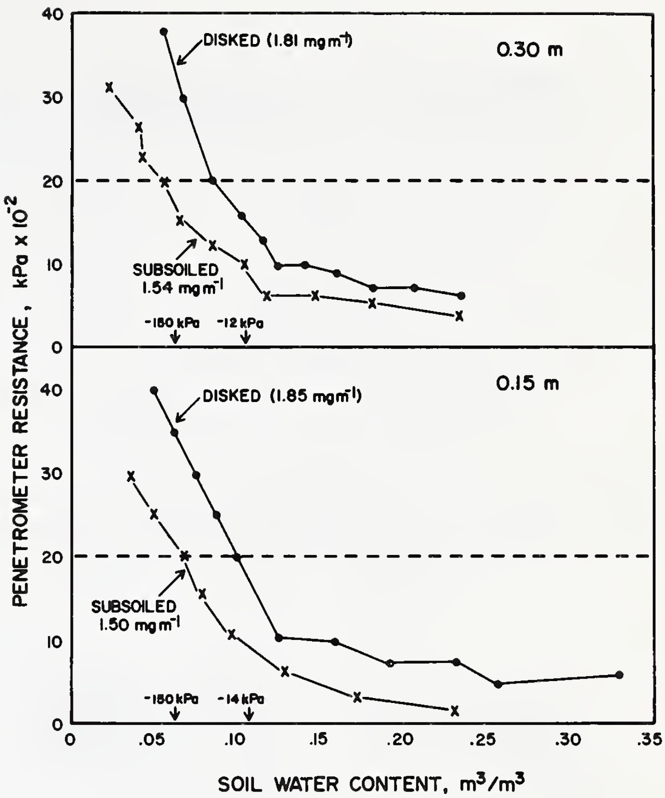

Figure 5.
Soil resistance measured by penetrometer as a function of water content for subsoiled, disked conditions and two soil horizons, Ap (0.15 m) and E (0.30 m). Arrows indicate water content and soil water pressure at which soil resistance equaled 2000 kPa.

Root Development

Root development for irrigated and nonirrigated corn with and without subsoiling on 28 May 1980 (60 days after planting) is shown in figure 6. For the disked, nonirrigated treatment, the corn roots were largely confined to the surface 0.15 m. In addition, very few roots had extended laterally to the midrows. For the disked, irrigated treatment, root density increased to a depth of 0.30 m, and more roots were measured in the midrows. A very different pattern was found where soil compaction was reduced by subsoiling. With the subsoiled, nonirrigated treatment, the root zone extended downward to 0.45 m, but there were few, if any, roots near the midrows. When subsoiling and irrigation were combined, the root system developed to a depth of at least 0.60 m, and there was a greater proliferation of roots toward the midrow, although almost none were measured at the midrow.

Two weeks later (11 June), the total root density of each treatment had increased, but the root system was still largely confined to the upper 0.30 m for the disked treatments (fig. 7). With subsoiling, the root system had extended to 0.75 m without irrigation and to 0.90 m with irrigation. Even with irrigation and subsoiling, root proliferation was not great in the midrows.

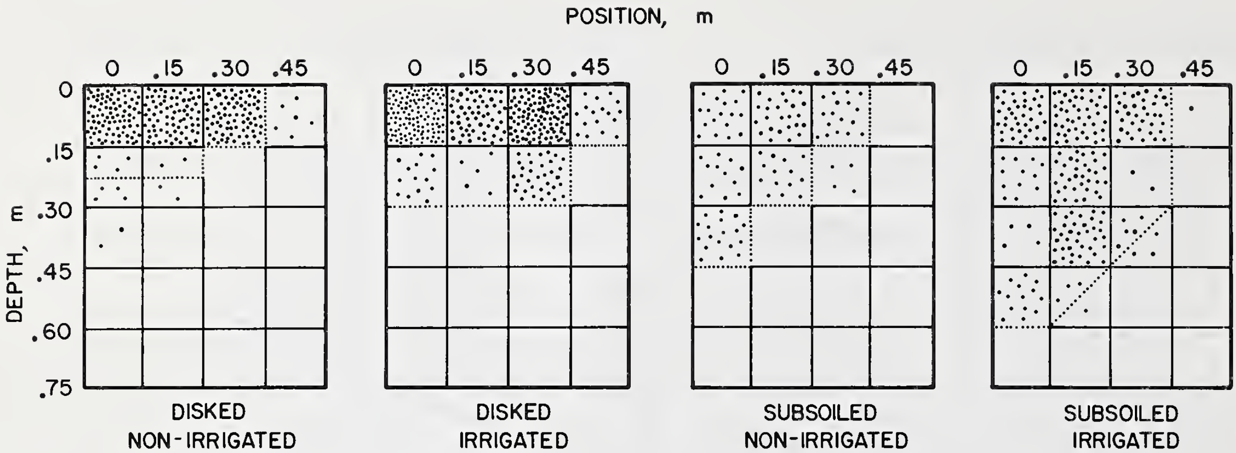

Figure 6.
Root distribution on 28 May 1980 as influenced by tillage and irrigation (D-NI = disked, nonirrigated; DI = disked, irrigated; SS-NI = subsoiled, nonirrigated; SS-I = subsoiled, irrigated). Each dot represents 0.50 m/m^3.

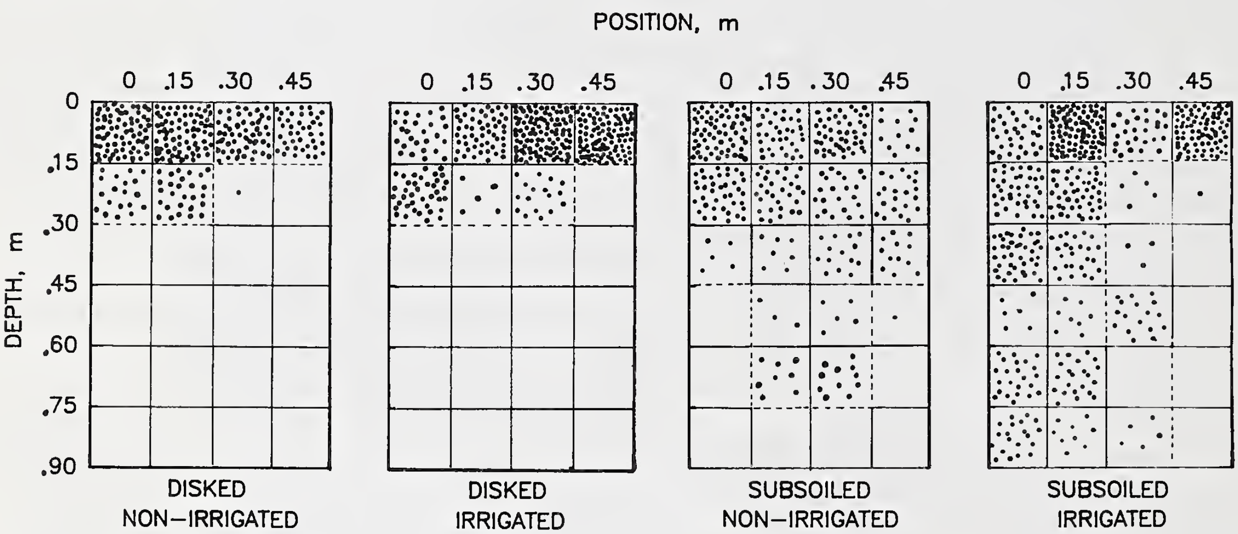

Figure 7.
Root distribution on 11 June 1980 as influenced by tillage and irrigation (D-NI = disked, nonirrigated; DI = disked, irrigated; SS-NI = subsoiled, nonirrigated; SS-I = subsoiled, irrigated). Each dot represents 0.50 m/m^3.

Even on 1 July 1980 during the grain-fill period, the root system of the disked treatment was still largely confined to the surface 0.30 m (fig. 8). The rooting system was better developed when irrigation was combined with subsoiling, but still only about 0.90 m of the 1.20-m profile had sufficient root growth to permit efficient water extraction.

The root density data show both the advantages and problems encountered with subsoiling in the Wagram soil. The narrow subsoil slit improved root distribution directly under the row; however, the soil volume between the rows was not as effectively exploited. Water held between the subsoil slits of the subsoiled treatment and water held below the 0.15-m depth of the disked treatment were not readily available to corn.

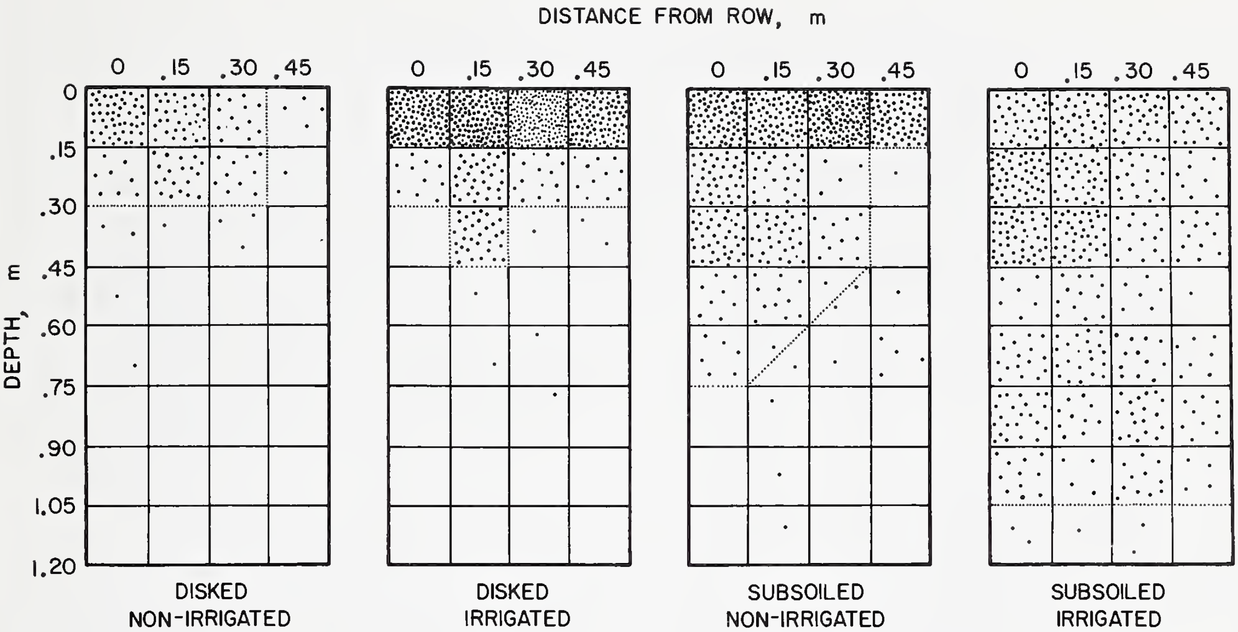

Figure 8.
Root distribution on 1 July as influenced by tillage and irrigation (D-NI = disked, nonirrigated; DI = disked, irrigated; SS-NI = subsoiled, nonirrigated; SS-I = subsoiled, irrigated). Each dot represents 0.50 m/m^3.

The maximum volume of water actually available to the plant at any time was estimated from root distributions and soil hydraulic properties. First, available water in the soil profile was determined as the difference between water content after 48 hours of drainage and the water content corresponding to an SWP of -100 kPa. For the profile extending to a 1.20-m depth, the potentially available water was 104 mm (table 3). Secondly, potentially available water of each 0.15- x 0.15-m cross-section of the root zone was considered available to the corn if the average root system in each section was significant. The available water was then summed over the 1.20-m profile for each date root observations were made. With the disked treatment, only 18% of the 104 mm of potentially available water could actually be considered available on 28 May. With an evapotranspiration (ET) rate of 6 mm/day only about 3 days' supply of available water was actually present for this treatment. Subsoiling alone or irrigation alone improved the root system and thus increased the amount of water available. A combination of the two treatments resulted in the most extensive root system, making 42% (43 mm) of the total water available.

The root system expanded with time, increasing the amount of water which could be available at any time (table 3). However, with the disked, irrigated treatment, only 6 days' supply of water could be held available by the time of grain fill as compared with 15 days' supply for the subsoiled, irrigation treatment -- assuming that all water is actually available at a rate sufficient to meet crop demands. In both disked and subsoiled tests, root development was more restricted in the nonirrigated treatments than in the irrigated treatments.

Table 3.
Available soil water for differing irrigation and tillage treatments on 3 dates during 1980 growing season

Depth	Available Water				
	Soil	D-NI*	D-I	SS-NI	SS-I
--m--	mm				
	5-28-80				
0- .15	18.7	15.5	18.7	15.5	15.5
.15- .30	17.8	2.9	14.7	8.9	14.7
.30- .45	13.8	--	2.3	2.3	9.2
.45- .60	10.9	--	--	--	3.7
.60- .75	11.4	--	--	--	--
.75- .90	9.7	--	--	--	--
.90-1.05	10.7	--	--	--	--
1.05-1.20	10.7	--	--	--	--
Total	103.7	18.4	35.7	26.7	43.1
%	100	18	34	26	42
	6-11-80				
0- .15	18.7	18.7	18.7	18.7	18.7
.15- .30	17.8	9.0	14.8	17.8	14.8
.30- .45	13.8	--	--	13.8	11.5
.45- .60	10.9	--	--	5.5	5.5
.60- .75	11.4	--	--	--	9.5
.75- .90	9.7	--	--	--	8.1
.90-1.05	10.7	--	--	--	--
1.05-1.20	10.7	--	--	--	--
Total	103.7	27.7	33.5	61.6	68.1
%	100	27	32	59	66
	7-1-80				
0- .15	18.7	15.5	18.7	18.7	18.7
.15- .30	17.8	14.7	17.8	14.7	17.9
.30- .45	13.8	--	2.3	11.5	13.8
.45- .60	10.9	--	--	7.3	10.9
.60- .75	11.4	--	--	3.8	11.4
.75- .90	9.7	--	--	--	9.7
.90-1.05	10.7	--	--	--	10.7
1.05-1.20	10.7	--	--	--	--
Total	103.7	30.2	38.8	56.0	93.1
%	100	29	37	54	90

* D-NI = disked, nonirrigated;
D-I = disked, irrigated;
SS-NI = subsoiled, nonirrigated;
SS-I = subsoiled, irrigated.

Soil Water Extraction Patterns and Rates

Soil water extraction patterns and rates of extraction in four irrigation-tillage treatments are shown in figures 9 and 10 for three 3-day periods from 26 June to 5 July 1979, when water uptake rates were at or very near maximum. The extraction patterns agree very well with the rooting depths shown previously. No rainfall occurred during this 9-day period, but rainfall had been sufficient during the preceding week so that corn was not severely stressed in any of the treatments.

For the disked, nonirrigated treatment (fig. 9A), water extraction was limited almost entirely to the surface 0.45 m. Calculated average ET rates decreased until between days 6 and 9. On day 9, the average ET was only 1.9 mm/d, which was only 24% of open pan (OP) evaporation. Calculated flux into the root zone was found to be very nearly zero. Although a significant upward gradient existed, the hydraulic conductivity was too low for measurable flux.

Average ET rates were maintained at about 75% of OP evaporation for the disked, irrigated treatments (fig. 9B). While the extraction was still limited to the surface 0.45 m, soil water contents were well maintained with irrigation; and extraction rates were about three times greater for the disked, irrigated treatment during the third 3-day period than for the disked, nonirrigated treatment.

Extraction patterns were influenced more by subsoiling than by irrigation, as was shown with the rooting patterns. During the first 3-day period of ET, extraction took place to a depth of 0.90 m for the subsoiled, nonirrigated treatment, although more than 90% of the water was extracted above 0.60 m (fig. 10A). Evapotranspiration rates during this period were 92% of OP evaporation. During the following 6 days, extraction rates were greatly reduced in the surface 0.45 m. Although root measurements indicated good root growth at depths greater than 0.45 m, total extraction rates decreased during the 6-day period after the water pressure in the surface 0.45 m decreased below -20 kPa. During the third period, average ET decreased to 4.3 mm/d, or 60% of OP evaporation. Measurements at other times in this experiment showed that optimum ET could not be maintained by extraction below 0.45 m.

During this same period, the average ET of the subsoiled, irrigated corn ranged between 88% and 98% of OP evaporation (fig. 10B). More than 75% of the water was extracted above the 0.45-m depth, although these data show a more uniform extraction pattern through the 0.90-m depth than did data for the subsoiled, nonirrigated treatment.

Grain Yields

Corn grain yields were significantly increased by subsoiling in both 1979 and 1980 (table 4). As discussed earlier, subsoiling provided deeper rooting and more available water. With a restricted root system below the 0.30-m depth for the disked treatments, management of water and nitrogen was not sufficient to permit optimum yields. Nitrogen was provided once by preplant broadcasting and again by a sidedress application. In the disked treatment, there was no doubt that both water and nitrogen were limited.

Maximum yields were obtained with a combination of subsoiling and irrigation (table 4). Similar irrigation-tillage experiments with soybean showed that subsoiling was not necessary if the SWP within the surface 0.45 m was maintained higher than -20 kPa (Quisenberry and Musen 1983). The results of the experiments with corn differ from those of the soybean experiments on the importance of subsoiling.

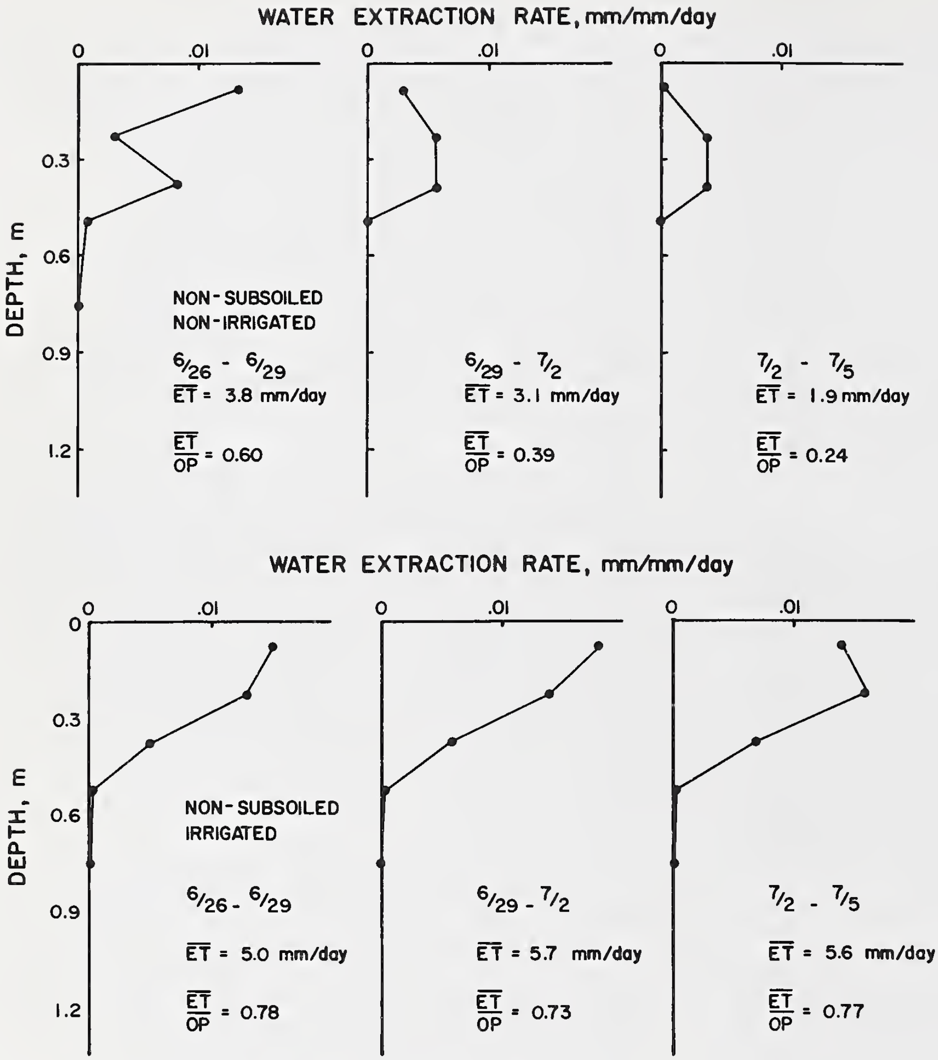

Figure 9.
Soil water extraction rate with depth during three 3-day intervals in 1979 for two irrigation-tillage treatments: A = disked, nonirrigated and B = disked, irrigated. Values also shown for average evapotranspiration ($\overline{ET}$) and for $\overline{ET}$ divided by open pan (OP) evaporation.

Applying irrigation when the SWP was −20 kPa rather than −100 kPa increased grain yield by about 2.5 Mg/ha. As has been shown with the extraction rates, corn became somewhat stressed as the SWP in the surface 0.30 m of soil decreased below about −20 kPa. When comparing yield data with measurements of ET rates, it would appear that ET needs to be maintained at about 90% of OP evaporation for maximum yields. Any time SWP in the surface 0.45 m decreased below about −20 kPa, the ET rate decreased rapidly.

Yields for the CBWB-irrigated, subsoiled treatment were comparable to those obtained when water was applied at −100 kPa (table 4). This is in good agreement with SWP patterns. Soil water pressures were generally in the −50 to −100 kPa

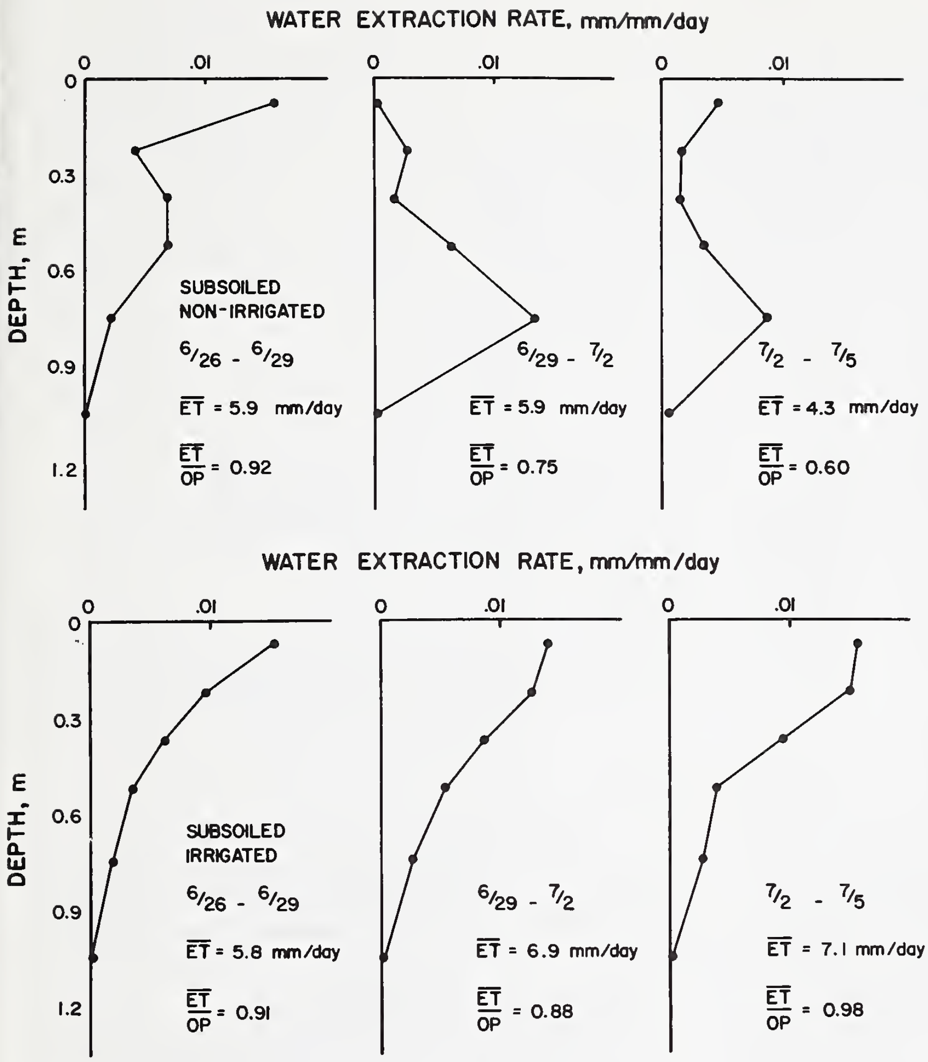

Figure 10.
Soil water extraction rate with depth during three 3-day intervals in 1979 for two irrigation-tillage treatments: A = subsoiled, nonirrigated and B = subsoiled, irrigated. Values also shown for average evapotranspiration ($\overline{ET}$) and for $\overline{ET}$ divided by open evaporation.

range before water was applied by the CBWB procedure. The application of water at these SWPs was due largely to the fact that during the first 2 years of the experiment, the root zone was defined as the maximum depth at which roots were observed. Thus, if roots were observed at a depth of 0.90 m, the root zone was defined as 0.90 m, with no consideration for the fraction of soil profile not occupied with roots. If irrigation had been called for when 50% of the available water was depleted, the surface 0.45 m would have had an SWP of less than -20 kPa. Yields for the three irrigation treatments under the disked tillage conditions were very similar. In these cases, the root system was very shallow and the depth at which irrigation was monitored or scheduled was very shallow. Therefore, all of these treatments received irrigation much more frequently.

Table 4.
Corn grain yields on Wagram sand for differing irrigation and tillage treatments

Tillage	Irrigation	Year 1979	1980	1981	Mean
		-----------	Mg/ha	-----------	
Disked	None	4.96	1.13	-----	3.05
	-20 kPa	5.53	6.59	-----	6.06
	-100 kPa	5.59	4.65	-----	5.12
	CBWB	6.03	6.34	-----	6.19
	Mean	4.03	4.68	-----	4.36
Subsoiled	None	7.16	4.77	6.27	4.36
	-20 kPa	8.79	10.42	8.74	9.32
	-100 kPa	6.53	6.59	7.22	6.78
	CBWB	7.91	6.78	6.90	7.20
	Mean	7.91	7.14	7.28	7.34
	LSD(0.05)	1.11	0.86	0.70	1.01

Another factor that should be considered is the actual amount of ET. Measurements made during all three seasons indicate that for the period of maximum water uptake by corn, the ratio of the average ET to OP evaporation should have been between 0.9 and 1.0. This is somewhat higher than that required by the CBWB procedure.

Figure 11 shows the ratio of the calculated ET to OP evaporation for three treatments during the period from 80 to 105 days after planting. When SWP was maintained greater than -20 kPa, the ratio ranged between 0.84 and 1.02. For both the nonirrigated treatment and the CBWB procedure treatment, the range was much greater. Although ratios of 0.9 or greater were calculated at different times, many of the values were less than 0.75. These data, coupled with the yield data, suggest that SWP must be maintained at -20 kPa or greater and that for maximum yield, the ratio of ET to OP evaporation must be approximately 0.9.

SUMMARY AND CONCLUSIONS

The influence of water management and tillage on corn yield was measured for 3 years on a Wagram sand at Blackville, SC. The Wagram sand contains a very-high-bulk-density layer which can extend from about 0.10 m to a depth of 0.60 m or greater. Bulk densities in the lower Ap horizon and throughout the E horizon were usually greater than 1.75 Mg/m^3.

These results show that subsoiling is necessary for maximum yields even with irrigation. This is in direct conflict with results reported by Quisenberry and Musen (1983) for soybean in which they showed that subsoiling was not necessary if irrigation was applied when the soil water pressure (SWP) decreased to -20 kPa at the 0.30-m depth. Measurements of

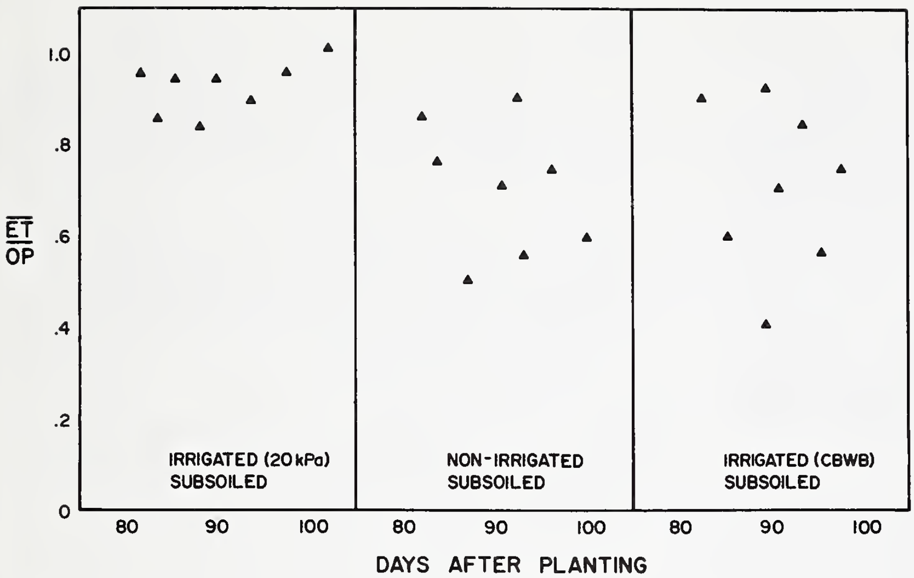

Figure 11.
Ratio of calculated ET to open pan evaporation for three treatments during a period from 80 to 105 days after planting. Negative sign omitted in soil water pressure value.

corn rooting depth indicate that very few roots were able to penetrate below the 0.15-m depth even with irrigation. Soil strength measurements made by a penetrometer indicated that resistance was greater than 2000 kPa at an SWP of less than -14 kPa. Without subsoiling, better management of water and nitrate within the surface 0.15 m would have been required to obtain yields comparable to those obtained with subsoiling.

When averaged across tillage treatments, corn grain yield increased about 3 Mg/ha with irrigation. In the subsoiled treatment, maximum corn yields were obtained when irrigation was applied as soon as SWP decreased to -20 kPa in the upper 0.45 m of soil. Withholding irrigation until SWP decreased to -100 kPa resulted in a yield decrease of 2.54 Mg/ha (9.32 as compared to 6.78 Mg/ha).

Corn yields were significantly lower with the CBWB treatment than with the -20 kPa treatment and were comparable to the -100 kPa treatment under subsoiled conditions. Two factors probably account for the lower yield with CBWB: (1) The root zone depth was overestimated with the CBWB. Available water was calculated by CBWB using the maximum depth of observed roots plus an additional 0.10 m of depth. During the critical stages of corn growth, rooting depths greater than 1.00 m were specified for the CBWB procedure. Under these conditions, soil water depletion was too great in the surface 0.60 m for optimum water uptake to take place. Yields for the CBWB and -20 kPa treatments were comparable in the disked treatment where the rooting zone for CBWB was restricted to a much shallower depth throughout the season. (2) CBWB assumes that maximum ET will be about 80% of open-pan (OP) evaporation. Evapotranspiration values calculated from soil water measurements indicated that maximum water uptake was approximately 100% of OP evaporation. With the -20 kPa treatment, ET/OP was always 0.8 or greater while with the CBWB treatment the ratio often was below 0.6.

This study showed that for soils such as Wagram, subsoiling is necessary for maximum corn yield. Irrigation management should be based on a system that will ensure that the SWP is maintained greater than -20 kPa in the upper 0.60 m of the soil profile.

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7. TIFTON, GEORGIA

J.E. Hook and E.D. Threadgill[1]

INTRODUCTION

During the 1970 to 1980 decade, the amount of land under irrigation in Georgia increased almost sevenfold from 59,000 ha to 385,000 ha.[2] By 1980, approximately 122,000 ha was irrigated and used for corn. With the rapid growth of irrigated cornlands in the State, there was a demand for irrigation scheduling techniques which would reliably and efficiently indicate water needs of the crop.

The objectives of the study reported herein were (1) to compare corn growth and yield when irrigation was scheduled by the computer-based water balance (CBWB) model versus a tensiometer method (TENS), (2) to compare soil water content (SWC) predicted by the CBWB model with observed values, (3) to conduct sensitivity analyses of soil and plant factors used within the CBWB model, and (4) to develop field experience with inputs and management of the CBWB model.

METHODS

Experimental Design

Evaluation of the CBWB model was conducted during the 1979 to 1982 growing seasons. Three sites near the Coastal Plain Experiment Station (CPES), Tifton, GA, were used. The CPES Irrigation Research Farm (IRF), the first site, was located on Lakeland sand (thermic, coated, Typic Quartzipsamment) and Bonifay sand (loamy, siliceous, thermic, Grossarenic Plinthic Paleudult). Both soils have sand texture to a depth of 1.2 m or more. In the Bonifay soil, plinthic horizons occur with an accumulation of clay below 1.2 m. The second site was the CPES Gin House Field (GHF), which is located on a Tifton loamy sand (fine loamy, siliceous, thermic, Plinthic Paleudult). The B horizon occurs at the 0.2- to 0.4-m depth. The third site was also located on a Tifton loamy sand at the Rural Development Center (RDC).

The irrigation system at the IRF and GHF sites had medium-pressure (276 kPa) impact sprinklers arranged on a 12.2-m x 12.2-m grid, providing individual plots 12.2 m x 12.2 m in size. Irrigation on individual plots was supplied by two sprinklers positioned on diagonally opposing corners of the plot. Under conditions of no wind, this created an approximate 36-m^2 area around the center of the plot with a relatively uniform application of water. All measurements were made within this area. All replicates of a given treatment were irrigated simultaneously. The amount of irrigation water applied to an individual plot was determined by the duration of sprinkler operation. Application amounts reported assume that 80% of the water delivered by the sprinklers actually reached the soil. The actual amount undoubtedly varied, depending upon prevailing weather conditions. Whenever possible, water was applied during morning hours or when wind was slight.

In addition to the irrigation system, the GHF site had tile drainage. Tile lines were 1.5 to 1.7 m deep to eliminate perched water above the dense C horizon. Tile lines were 12.2 m apart, located under the sprinkler system laterals. The close spacing assured rapid drainage after excessive rainfall.

The RDC site was irrigated by a center pivot system. The 6.5-ha site was divided into quarter circles, only one quarter of which had corn during the 2 years of

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[2]Georgia Extension Service Annual Irrigation Survey.

tests at the site. Within the corn quarter circle, sixteen 11- x 23-m plots contained tillage treatments. For the two tests at this site -- RDC4 and RDC2 -- the CBWB model was used to schedule irrigation for the entire quarter circle on a grower consultant basis. Crop management and the tillage study were handled by another research group. They were given information on when and how much to irrigate based on the CBWB model output.

No attempt was made to measure or to control runoff. The Tifton soil sites had a uniform 2% slope. Runoff occurred with intense showers particularly when surface crusting existed. The Bonifay soil site was mostly level. With the excessive internal drainage of this soil, runoff rarely occurred. On both soils, there was no runoff during irrigation.

At the IRF and GHF sites, nine replicated irrigation comparisons involving the CBWB model were conducted. Table 1 summarizes the basic crop management information for each of those tests. Table 2 provides experimental design and treatment information. Each of the plot designs involved other irrigation treatments and hypotheses not directly involved in this study; they are not discussed herein. In each study, the CBWB model irrigation treatment was compared with the shallow tensiometer (TENS) irrigation treatment using the null hypothesis. For TENS, irrigation was applied whenever more than half of the tensiometers in the 0.15- to 0.30-m soil-depth zone indicated soil water pressure was less than -30 kPa. In seven of the nine tests, a nonirrigated check was included. The check was managed with the same population and fertilization as the irrigated treatments.

In 1979, for tests GRKM and HOK1, the CBWB model was evaluated by predicting water requirements and soil water content for a treatment where irrigation was actually controlled by tensiometers. The information on soil water limits and root depth gathered during these tests was used in subsequent trials.

Sampling Methods

Soil samples were taken via orchard augers from each replicate to provide initial gravimetric soil water content (GWC) for the model and for periodic checks and reinitialization. At reinitialization, the model's calculated values of soil water content (SWC) for the sampling date were dropped, and the measured values were substituted. Subsequent additions and withdrawals were added to or subtracted from the new value. During the 1980 and 1981 tests, GWC was determined approximately monthly; however, those values were used for reinitialization only twice per test. In 1982 each test was sampled every 2 to 3 weeks, and the model was reinitialized following each sampling.

Soil water pressure was observed early each morning from 30 days after planting until black layer formation was observed in the corn grain. Tensiometers were placed near the center of the plot in two to four replicates of each treatment in each test. They were located 0.15 m from the corn row at depths of 0.10, 0.20, 0.30, 0.45, 0.60, 0.75, 0.90, and 1.2 m. Soil water pressure was measured by means of mercury manometers located at the edge of those plots. Gypsum blocks were located 0.3 m from the corn row at depths of 0.15, 0.30, 0.45, 0.60, and 0.75 m to provide a measure of soil water pressure beyond the -60 kPa range of the tensiometers.

Throughout these studies there were two uses of tensiometer readings. First, pressure readings of the 0.15- and 0.30-m depths were used directly for scheduling TENS irrigation. Second, pressure readings from the 0.10- to 1.2-m depths were

Table 1.
Crop management and growth conditions for all tests at the Tifton (CPES) GA location

Test Code	Field* Site	Soil Type	Tillage**	Total Fertilizer Addition N	P	K	Mg	S	Zn	Harvest Population	Corn Hybrid	Dates Planting	Emergence	Silk	Black Layer	Harvest	Year
				---------- kg/ha ----------						Plants/ha							
GRKM	IRF	Lakeland	MP	280	85	180	38	129	12	60,200	Pioneer 3369A	22 Mar	31 Mar	29 May	5 Jul	31 Jul	1979
HOK1	GHF	Tifton	CH	216	10	37	3	16	0	69,200	Pioneer 3369A	9 Mar	16 Mar	25 May	30 Jun	10 Jul	1979
GRG	IRF	Bonifay	SP	278	86	226	53	180	12	60,100	Funks G5407A	24 Mar	2 Apr	4 Jun	11 Jul	15 Jul	1980
GRG2	IRF	Bonifay	MP	274	60	225	52	129	6	56,300	Funks G4507A	11 Mar	26 Mar	1 Jun	2 Jul	14 Jul	1981
GRG1	IRF	Bonifay	MP	257	59	216	66	107	6	74,200	Funks G4507A	14 Apr	20 Apr	22 Jun	27 Jul	4 Aug	1981
B23	GHF	Tifton	MP	274	60	225	52	130	6	57,000	Funks G4507A	12 Mar	---	28 May	1 Jul	13 Jul	1981
RDC4	RDC	Tifton	MP vs SP	315	6	140	24	32	3	69,200	Funks G4507A	16 Mar	1 Apr	1 Jun	5 Jul	20 Jul	1981
GRI1	IRF	Bonifay	MP	315	58	202	43	113	6	82,700	DeKalb XL71	10 Mar	18 Mar	31 May	6 Jul	13 Jul	1982
GRI2	IRF	Bonifay	MP	315	58	202	43	113	6	83,400	DeKalb XL71	10 Mar	18 Mar	31 May	6 Jul	13 Jul	1982
B1	GHF	Tifton	MP	315	25	202	43	113	6	87,600	DeKalb XL71	10 Mar	18 Mar	28 May	6 Jul	14 Jul	1982
RDC2	RDC	Tifton	MP vs SP	248	31	162	4	5	0	80,200	Funks G4507A	16 Mar	22 Mar	1 Jun	5 Jul	15 Jul	1982

* IRF - Irrigation Research Farm; GHF - Gin House Field;
RDC - Rural Development Center center pivot area.

** MP - Moldboard plow, 250 mm deep; CH - chisel plow, 250-mm-deep shanks 250 mm apart; SP - in-row subsoil-planting, subsoil 350 mm deep.

Table 2.
Experimental design and CBWB inputs

Test			Irrigation Treatments**				Soil Layer		Available Water		Allowable Depletion		Root Depth	
Code	Layout*	Reps	CBWB	TENS	NI	Others***	From	To	UL	LL	From	Amount	From	Amount
		No.				No.	mm		----- mm -----			%		mm
GRKM[+]	RCB W/ Split plots	3	---[‡]	Yes	Yes	26	0	300	.089	.019	30 May	50	30 May	450
							300	600	.094	.026			19 June	600
HOK1[+]	CRD	4	---[‡]	Yes	Yes	11	0	300	.190	.050	2 June	30	2 June	457
							300	450	.240	.096	21 June	50	19 June	610
							450	750	.240	.096				
GRG	CRD	5	Yes	Yes	Yes	3	0	150	.170	.025	4 Apr	65	4 Apr	152
							150	300	.170	.023	11 May	50	28 Apr	305
							300	600	.170	.027			13 May	457
							600	750	.170	.023			26 May	762
GRG2	LS	4	Yes	Yes	Yes	1	0	230	.17	.025	27 Mar	50	27 Mar	102
							230	304	.17	.023	13 Apr	70	5 Apr	152
							304	457	.17	.023	27 Apr	50	10 Apr	203
							457	1220	.17	.023			14 Apr	254
													17 Apr	406
													12 Apr	508
													19 May	635
GRG1	LS	4	Yes	Yes	No	2	0	230	.17	.025	30 Apr	50	30 Apr	102
							230	305	.17	.023			8 May	203
							305	457	.17	.023			15 May	305
							457	1220	.17	.023			22 May	457
													9 Jun	610
													10 Jun	635
B23	RCB	5	Yes	Yes	Yes	3	0	76	.118	.039	31 Mar	30	31 Mar	100
							76	229	.164	.065	13 Apr	70	5 Apr	150
							229	457	.200	.092	21 May	50	9 Apr	200
							457	1220	.277	.090			14 Apr	250
													17 Apr	356
													1 May	406
													12 May	483
													19 May	610
RDC4	RCB	4	Yes	No	No	3	0	76	.118	.039	14 Apr	50	14 Apr	100
							76	229	.164	.065			17 Apr	355
							229	457	.200	.092			12 Apr	483
							457	1220	.277	.090			19 May	610

GRI1	LS	4	Yes	Yes	Yes	1	0	102	.110	.025	23 Apr	50	23 Apr	300
							102	152	.110	.025			7 May	400
							152	229	.110	.025			14 May	600
							229	304	.110	.025			19 May	750
							304	457	.110	.025				
							457	609	.110	.025				
							609	762	.100	.025				
							762	914	.100	.025				
GRI2	LS	4	Yes	Yes	No	2	0	102	.110	.025	23 Apr	70	23 Apr	300
							102	152	.110	.025			7 May	400
							152	229	.110	.025			14 May	600
							229	304	.110	.025			19 May	750
							304	457	.110	.025				
							457	609	.110	.025				
							609	762	.100	.025				
							762	914	.100	.025				
B1	RCB	4	Yes	Yes	Yes	2	0	102	.135	.053	23 Apr	50	23 Apr	300
							102	152	.145	.053			7 May	350
							152	229	.138	.065			14 May	600
							229	304	.165	.065			19 May	750
							304	457	.200	.100				
							457	609	.250	.100				
							609	762	.250	.100				
							762	914	.250	.100				
RDC2	RCB	8	Yes	No	No	1	0	102	.135	.053	23 Apr	70	23 Apr	300
							102	152	.145	.053	14 May	50	3 May	400
							152	229	.138	.065			14 May	600
							229	304	.165	.065			19 May	750
							304	457	.200	.100				
							457	609	.250	.100				
							609	762	.250	.100				
							762	914	.250	.100				

* RCB - Randomized complete block; CRD - completely randomized; LS - Latin square.

** CBWB = Computer-based water balance, TENS = tensiometer, NI = nonirrigated.

***Other treatments included delayed irrigation, deficit irrigation, and deep tensiometer (Hook 1985).

\+ Test GRKM and HOK1 contained fertility, irrigation and tillage variables. Only the medium fertility - moldboard plow tillage treatment was included in these tests.

‡ The model was not actually controlling irrigation treatments but was run using the TENS treatment data.

used, in conjunction with the root depth, to calculate the water content of the root zone. This tensiometer water content (TWC) was then used in comparisons with CBWB-predicted water content (SWC) and gravimetrically measured water content (GWC). Tensiometer readings were used for evaluating status of soil water pressure in the CBWB treatment. No pressure data are presented, but some general comments regarding those readings are made in evaluating the CBWB treatment.

Irrigation amounts were calibrated according to both nozzle discharge and time. Effective irrigation was assumed to equal 80% of the sprinkler discharge. For all tests, the amount of water applied with each irrigation was fixed at 25 mm. The frequency rather than the amount was increased during the season. This method was selected because many grower irrigation systems lack the flexibility to apply amounts greater than 25 mm in any reasonable amount of time.

Meteorological observations for updating the CBWB model were taken from three stations, each of which was within 250 m of the respective field site. Temperatures were recorded using either thermocouples or mechanical thermographs. Solar radiation was measured at the RDC and GHF sites by an Epply black and white pyranometer and at the IRF site by a cosine-corrected silicon pyranometer. Rainfall and open pan evaporation were measured at each site daily at 0800 hours. Meteorological forecasts of maximum and minimum temperatures and solar radiation were supplied for the Tifton area by the National Weather Service in Columbia, SC.

Plant growth was observed at 2- to 3-week intervals from 1979 until 1981. Average crop height was measured until pollination. Leaf area was determined using a LiCor table-model area meter on four plants taken from each replicate of the CBWB model treatments. Biomass was also determined using those samples. Root depths used in the CBWB model were based on roots observed in excavations in two plots each week until pollination. Corn grain samples (2 row x 6.1 m) were taken by hand from the center bed of the five 1.8-m beds of each plot. Shelled samples were weighed and the weights adjusted for moisture to 15.5%.

Soil water limits used in the CBWB model were determined from moisture release curves obtained in the laboratory on undisturbed 3.47×10^5 mm^3 cores. For each soil layer, five or more cores were used, and a single curve was determined using a least squares regression fit of the data. The upper limit (UL) and lower limit (LL) values for use in the model were then taken as the WC values at equivalent pressures of 5 and 1500 kPa, respectively. In 1980 and 1981, the UL values obtained from moisture release curves were replaced by the UL values determined in situ by gravimetric sampling following 24 hours of drainage under plastic. In 1982 for the tests on the IRF site, the UL was lowered 6% for each layer because the CBWB model overpredicted the need for irrigation during the 1980 and 1981 tests at this site.

Values of TWC were calculated from the daily tensiometer measurements of soil water pressure by the polynomial equation

$$TWC = A_0 + A_1(LPSI) + A_2(LPSI)^2$$

where,

TWC is water content (volume basis--m^3/m^3) calculated from tensiometer readings

A_0, A_1, A_2 are zero-, first- and second-order coefficients of polynominals determined by least squares analysis for laboratory-measured water retention curves for each layer

LPSI = $\text{Log}_{10}[(-\text{PSI} + B)10^4]$
PSI = Observed soil water pressure (kPa at the tensiometer cup)
B = Adjustment factor to adapt lab curves to field use (2 kPa for Bonifay soil; 3 kPa for Tifton soil).

For PSI greater than -0.1 kPa, PSI was set equal to -0.1 kPa. For TWC calculated to be greater than the total porosity, TWC was set equal to the total porosity. Coefficients for the various soil layers have been previously published (Hook 1985).

RESULTS AND DISCUSSION

Yield and Irrigation Amounts

Corn yields for the 13 tests are provided in tables 3 through 6. For the five tests conducted on Bonifay soil (table 3), there was no significant difference between yields of the CBWB treatment and the TENS treatment over all tests or within any test. The low nonirrigated yields, however, clearly indicated that irrigation was needed each year. Both methods of irrigation produced equivalent yields.

Irrigation amounts varied considerably by year, by treatment, and by growth stage for tests on Bonifay soil (table 3). In the 1980 GRG test, more water was required by TENS than by CBWB prior to tasseling. As will be seen later, the CBWB was late in calling for irrigation throughout this period. However, four moderate and evenly spaced rainfall events supplied much of the corn water needs. Each of these events occurred after the TENS treatments had been irrigated. During pollination and grain fill, both methods required the same water application.

In the 1981 March-planted test, GRG2, the CBWB again required less water than TENS during the vegetative growth. However, in this test, the CBWB required more water during pollination and grainfill than the TENS. In the 1981 April-planted test, GRG1, and the 1982 March-planted test, GRI1, the CBWB required significantly more water during both growth stages than the TENS. In the 1982 March-planted GRI2 test, irrigation amounts were about the same for both methods. Test GRI2 differed from GRI1 only in the allowable depletion -- 70% for GRI2 and 50% for GRI1. For 1982, the former value resulted in better agreement for water requirements between the methods.

For the principal comparison tests on Tifton soil (table 4) the CBWB treatment resulted in a significantly higher yield than that for the TENS treatment in the 1981 test, B23, and the same yield as that for the TENS treatment in the 1982 test, B1. In the B23 test, the CBWB called for 40% more water than TENS; and in the B1 test, it called for 75% more water. With the improved yield of the CBWB treatment in B23, some additional water could be justified; however, yield was not improved in the B1 test.

In the center pivot studies (table 5), where irrigation was scheduled only by the CBWB, corn yields were in the same range as those in other tests on Tifton soil (table 4). The CBWB scheduling method worked as well in this center pivot area as it did at the treatment plots. Since the irrigation was applied uniformly over the whole center pivot area, yield differences shown are effects of tillage and population.

In the tests conducted early in 1979 (table 6), the CBWB scheduling began after pollination, and, rather than split the treatments previously scheduled by TENS, TENS treatments were continued. The CBWB merely provided an estimate of soil water (discussed later). The data in table 6 are provided as a reference to later discussions.

Table 3.
Corn grain yields and water additions to irrigation tests on Bonifay soil

Year	Test Code	Irrigation Treatment	Yield	Stage*	Seasonal Water Input Rain	Irrigation**	Total
			Mg/ha		---------- mm	----------	----------
1980	GRG	CBWB	8.4	V	342	62	404
				R	87	149	236
		TENS	9.1	V	342	137	479
				R	87	149	236
		NI***	2.2	V	342	37	379
				R	87	0	87
		LSD(.05)	2.9				
1981	GRG2	CBWB	10.9	V	162	160	322
				R	86	181	265
		TENS	10.1	V	162	220	382
				R	86	126	212
		NI	0.5	V	162	0	162
				R	86	0	86
		LSD(.05)	0.8				
1981	GRG1	CBWB	9.2	V	138	206	344
				R	119	149	268
		TENS	9.8	V	138	148	286
				R	119	89	208
		LSD(.05)	0.8				
1982	GRI1	CBWB	12.1	V	247	152	394
				R	240	120	390
		TENS	11.6	V	247	122	369
				R	240	66	296
		NI	6.6	V	247	55	302
				R	240	0	220
		LSD(.05)	1.1				
1982	GRI2	CBWB	12.6	V	247	152	399
				R	240	99	319
		TENS	13.4	V	247	156	403
				R	240	88	308
		LSD(.05)	1.2				

* V = planting to silk; R = silk to black layer.
** Includes water used with chemigation.
***NI = nonirrigated.

CBWB Predictions Versus Gravimetric Soil Water Content

The CBWB adequately scheduled irrigation for corn over several years. Operation of the CBWB requires input of upper and lower limits of available water for each soil layer of the root zone. Those limits are not sharply defined by any sampling procedure and are not readily available for many soils. Much of the investigation of the CBWB at Coastal Plains Experiment Station, Tifton, was to determine the accuracy of WC predictions by the CBWB using the UL and LL original-

Table 4.
Corn grain yields and water additions to irrigation tests on Tifton soil

Year	Test Code	Irrigation Treatment	Yield	Stage*	Seasonal Water Input Rain	Irrigation**	Total
			Mg/ha		----------	mm	---------
1981	B23	CBWB	12.1	V	178	158	336
				R	45	181	226
		TENS	10.5	V	178	119	297
				R	45	124	169
		NI***	4.7	V	178	20	198
				R	45	0	45
	LSD(.05)		1.2				
1982	B1	CBWB	12.3	V	236	122	358
				R	132	117	249
		TENS	12.5	V	236	84	320
				R	132	53	185
		NI	7.5	V	236	23	259
				R	132	0	132
	LSD(.05)		1.2				

* V = vegetative; R = reproductive.
** Includes water used with chemigation.
***NI = nonirrigated.

ly supplied and to determine the sensitivity of the predictions to changes in the UL and LL values. Further, to control cumulative errors in predictions, Lambert et al. (chapter 2) recommended reinitialization of the CBWB periodically. Part of this investigation examined the impact of this reinitialization on accuracy in the prediction of soil WC.

Gravimetric WC (GWC) values determined periodically during the season provided the first check for the CBWB. Figures 1 through 6 represent the CBWB predictions as each test was run during the original growing season. The GWC and SWC values represent the total water to the current rooting depth plus 0.1 m. Occasional corrections in the meteorological or irrigation records as originally reported were included in the input data before these output runs were generated. Each figure indicates the actual rainfall and irrigation from 20 days after planting (DAP) until 120 DAP. The latter time was always after black layer formation in the corn. Also indicated are the UL, CL, and LL, with CL indicating the percentage of allowable depletion (AD) in the rooting zone. Finally, to prevent duplication of figures, water contents calculated from tensiometer measurements (TWC) are included in figures 1-6. The values, called TWC, were calculated from tensiometers within the CBWB treatment plots and not from the TENS treatment plots. The comparison of TWC and CBWB-based, simulated WC (SWC) will be discussed later.

For the 1979 tests, GRKM and HOK1 (fig. 1A, 1B), the UL and LL limits were taken from laboratory-determined moisture release curves. For the Lakeland sand of GRKM, these limits appeared to be too

Table 5.
Corn grain yields and water additions to corn grown at the center pivot on Tifton soil

Year	Test Code	Treatments		Yield	Stage*	Seasonal Water Input		
		Tillage	Population			Rain	Irrigation**	Total
			plants/ha	Mg/ha		------------ mm ----------		
1981	RDC4	Moldboard plot	69,200	11.2	V	152	119	271
			88,900	11.5	R	51	179	230
		Subsoil plant	69,200	9.1	V	152	119	271
			88,900	10.6	R	51	179	230
		LSD(.05)		1.3				
1982	RDC2	Moldboard plot	82,000	12.6	V	254	144	398
					R	123	71	194
		Subsoil plant	82,000	13.4	V	254	144	398
					R	123	71	194
		LSD(.05)		1.2				

* V = vegetative; R = reproductive.
** Includes water used with chemigation.

Table 6.
Corn grain yields and water additions to corn tests used for the initial CBWB calibration in 1979 on Tifton and Lakeland soils

Soil	Test Code	Treatment	Yield	Stage*	Water added		
					Rain	Irrigation**	Total
			Mg/ha		------------ mm ------------		
Lakeland	GRKM	TENS	11.3	V	239	173	412
				R	117	93	210
		NI***	5.4	V	239	0	239
				R	117	0	117
Tifton	HOK1	TENS	10.7	V	184	226	410
				R	89	58	147
		NI	5.7	V	184	0	184
				R	89	0	89

* V = vegetative; R = reproductive.
** Includes water used with chemigation.
*** NI = nonirrigated.

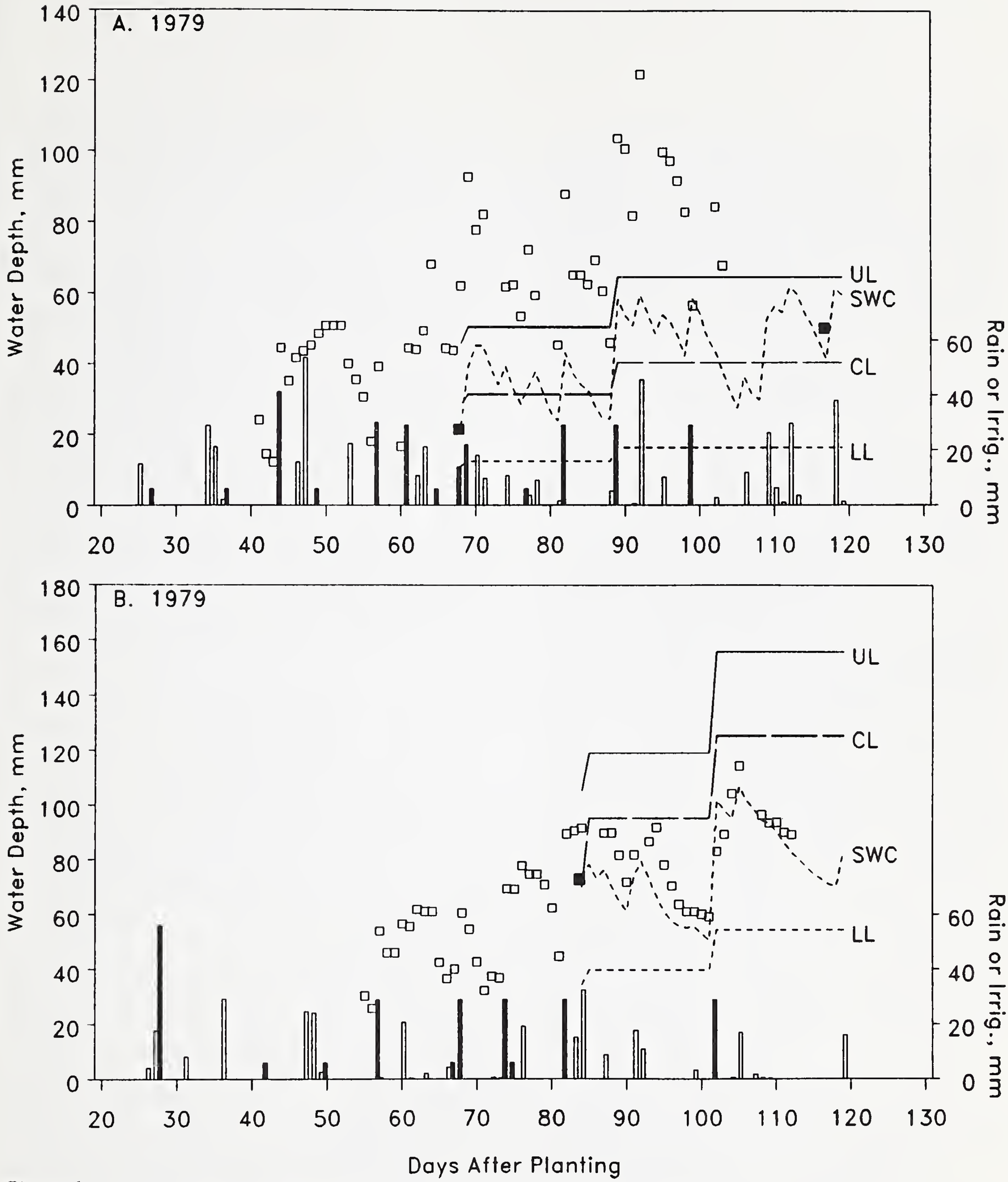

Figure 1.
Daily root-zone water content, irrigation, and rainfall data for (A) GRKM treatment and (B) HOK1 treatment at Tifton in 1979. Curves show the CBWB-based simulated water content (SWC), and the upper limit (UL), critical level (CL), and lower limit (LL) of available water; solid and open bars, respectively, show the amounts of irrigation (Irrig) or rain received; solid squares show the gravimetric water content (GWC); and open squares show the tensiometer-based calculated water content (TWC). Scale for bars shown on right vertical axis.

narrow. During drydown, predicted WC (that is, SWC) fell below CL 2 to 3 days before the need to irrigate was indicated by tensiometer readings. During rainfall or irrigation, SWC often exceeded UL, and excess water was generated. The calculated excess was subtracted, and then the predicted evapotranspiration (ET) was subtracted; so the final SWC always fell below UL. In subsequent years, the UL for the Lakeland and Bonifay sands was increased (table 2).

For the Tifton loamy sand of HOK1 (fig. 1B), SWC consistently fell at the lower end of available water. The tensiometer readings, however, indicated that irrigation was, in fact, not needed and, therefore, that both the UL and CL curves were too high. New UL values were obtained from additional moisture release curves for samples taken from more narrowly defined soil layers (table 2). In subsequent tests, the UL for the Tifton soil was decreased in the upper 0.45 m of soil.

The 1980 test, GRG (fig. 2), was the first complete test of the CBWB treatment for the early-season corn hybrids. During this test, located on Bonifay soil, corn roots were observed to increase to a depth of more than 1.2 m. Root depth data were updated in the CBWB model at 3-week intervals until the depth exceeded 0.75 m. This depth was considered to include most of the active water extraction zone. It was the deepest root depth used as input for the CBWB model. SWC was significantly greater than GWC on each sampling date. Largely as a result of the overprediction, no irrigation was recommended between 30 and 70 DAP even

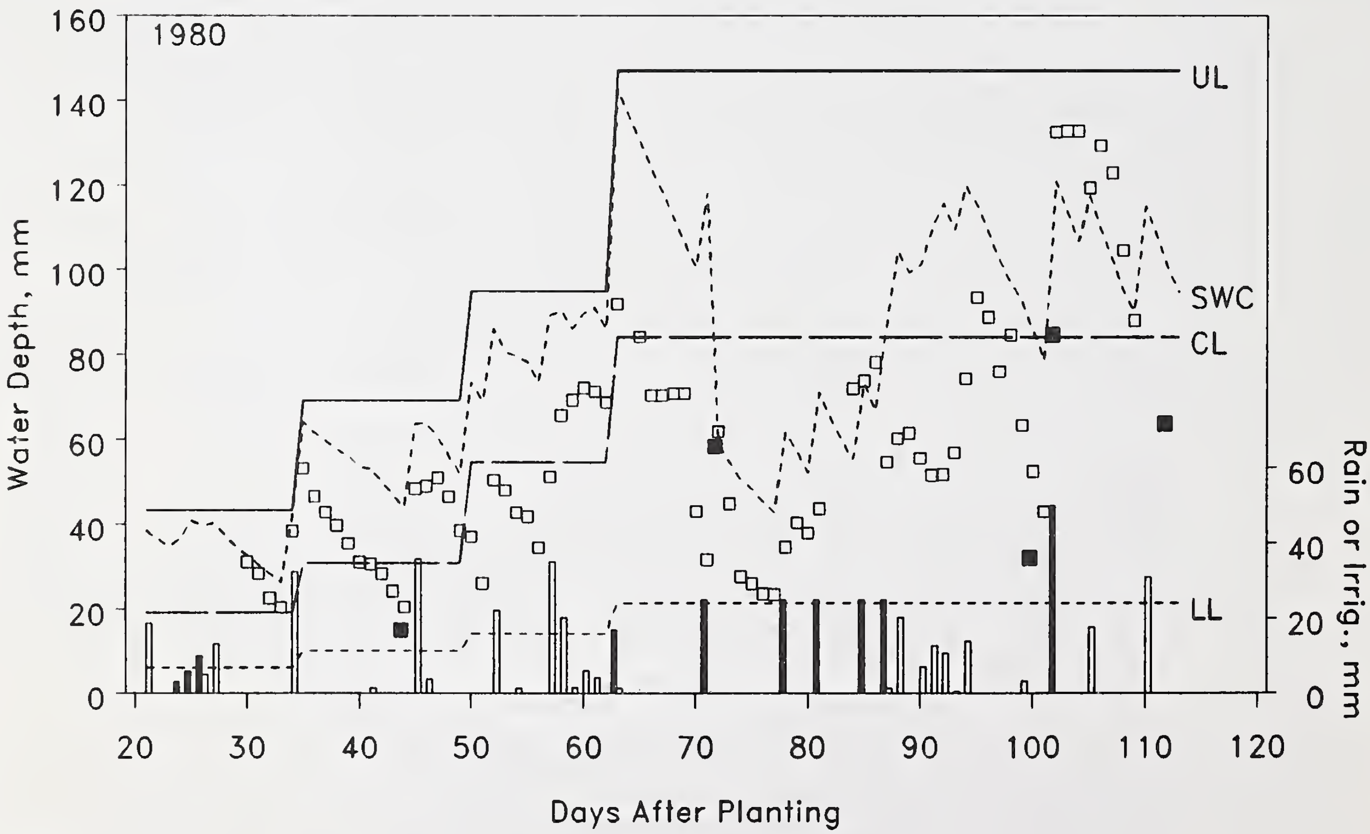

Figure 2.
Daily root-zone water content, irrigation, and rainfall data for GRG treatment at Tifton in 1980. See figure 1 for explanation of symbols.

though tensiometer readings were regularly indicating a need for irrigation. Visual stress symptoms were evident between days 40 to 45 and days 65 to 70. However, well-spaced rainfall aided the crop until 60 DAP, when a 25-day rainless period began. Because rooting had just been increased to 0.75 m and because the CBWB was overestimating the available water, no irrigation was requested until the CBWB was reinitialized on day 71. The SWC remained below the CL until about 85 DAP because the depleted water was not completely replaced. Irrigation amounts were constant and were just enough to replace water lost between the CBWB runs every 3 or 4 days. The CBWB continued to overestimate available water content, and errors accumulated by sampling days 100, 102, and 112. While SWC values were consistently high in this test, rainfall and irrigation events were frequent enough to prevent serious yield reductions (table 3).

The 1981 tests, GRG2 and GRG1, located on Bonifay soil, used the same UL and LL values that were used in the 1980 test, GRG. As in 1980, the SWC values were consistently higher than GWC values (fig. 3A, 3B). The growing season of 1981, however, had little rainfall to overcome the CBWB's shortfall on early-season irrigation. For GRG2, irrigation was begun after the first reinitialization (48 DAP), and it was scheduled regularly thereafter. The SWC never increased much above CL, so irrigation was indicated in each 3- to 4-day CBWB run. In effect, this was a deficit irrigation technique, since the soil was never completely refilled to the UL. Later, soil samplings confirmed that the CBWB continued to overestimate WC. Test GRG1, planted in April, behaved similarly. With two reinitializations, irrigations were indicated at almost all CBWB runs. In spite of this, SWC was always greater than GWC.

For the 1981 tests, B23 and RDC4, located on Tifton soil, there was generally good agreement between SWC and GWC for each observation date (fig. 4A, 4B). There were minor adjustments in SWC at the time of reinitialization. Irrigations were recommended regularly; and, as in the previous tests, irrigation seldom replaced all of the water depleted from the root zone.

For 1982, several changes were instituted to help improve predictions of WC for the Bonifay soil (table 2). Soil layer thickness was decreased to 75 mm; the same increment as that used in soil moisture sampling. The UL was decreased, and the CBWB model was reinitialized every 2 to 3 weeks. These changes were based more on trial and error than on measurements.

The effects of these changes for Bonifay soil were evident in tests GRI1 and GRI2 (fig. 5A, 5B). There was generally very good agreement between SWC and GWC for all dates in both tests. For the corn-growing season, 1982 had above average rainfall; however, corn yield was still increased by irrigation (table 3). With generally accurate predictions of WC, both the 50% AD (GRI1) and the 70% AD (GRI2) produced high yields, but the 70% AD required less water. It would appear that with accurately predicted SWC, a 70% AD would effectively schedule irrigations. On the other hand, when SWC was overestimated, the 50% AD may have helped schedule irrigations frequently enough to prevent yield loss.

For the Tifton soil in 1982, as in previous years, the tests B1 and RDC2 had generally good agreement between SWC and GWC (fig. 6A, 6B). Only the 70 DAP reinitialization for B1 required a major adjustment, as the SWC was considerably lower than the GWC.

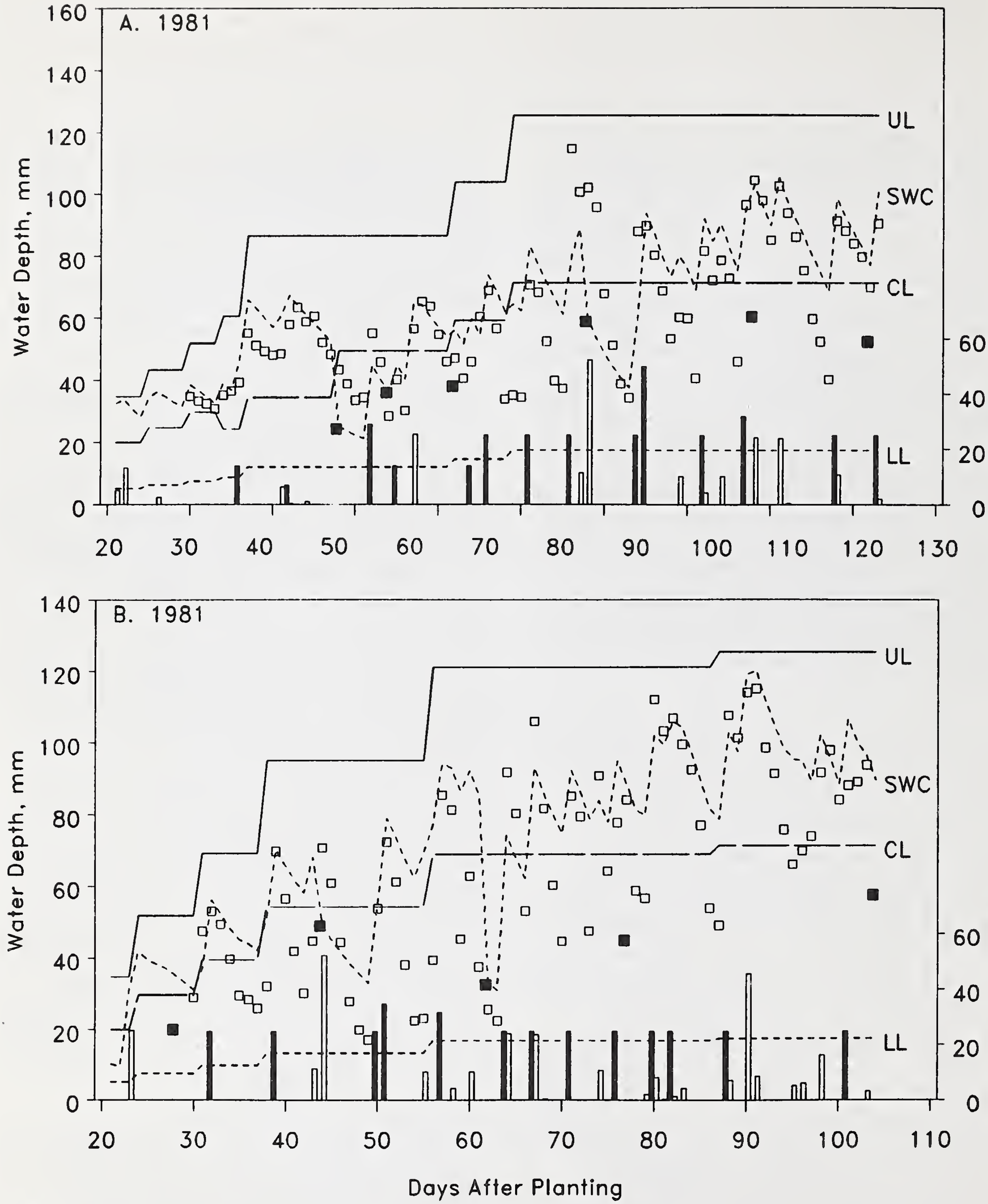

Figure 3.
Daily root-zone water content, irrigation, and rainfall data for (A) GRG2 treatment and (B) GRG1 treatment in 1981. See figure 1 for explanation of symbols.

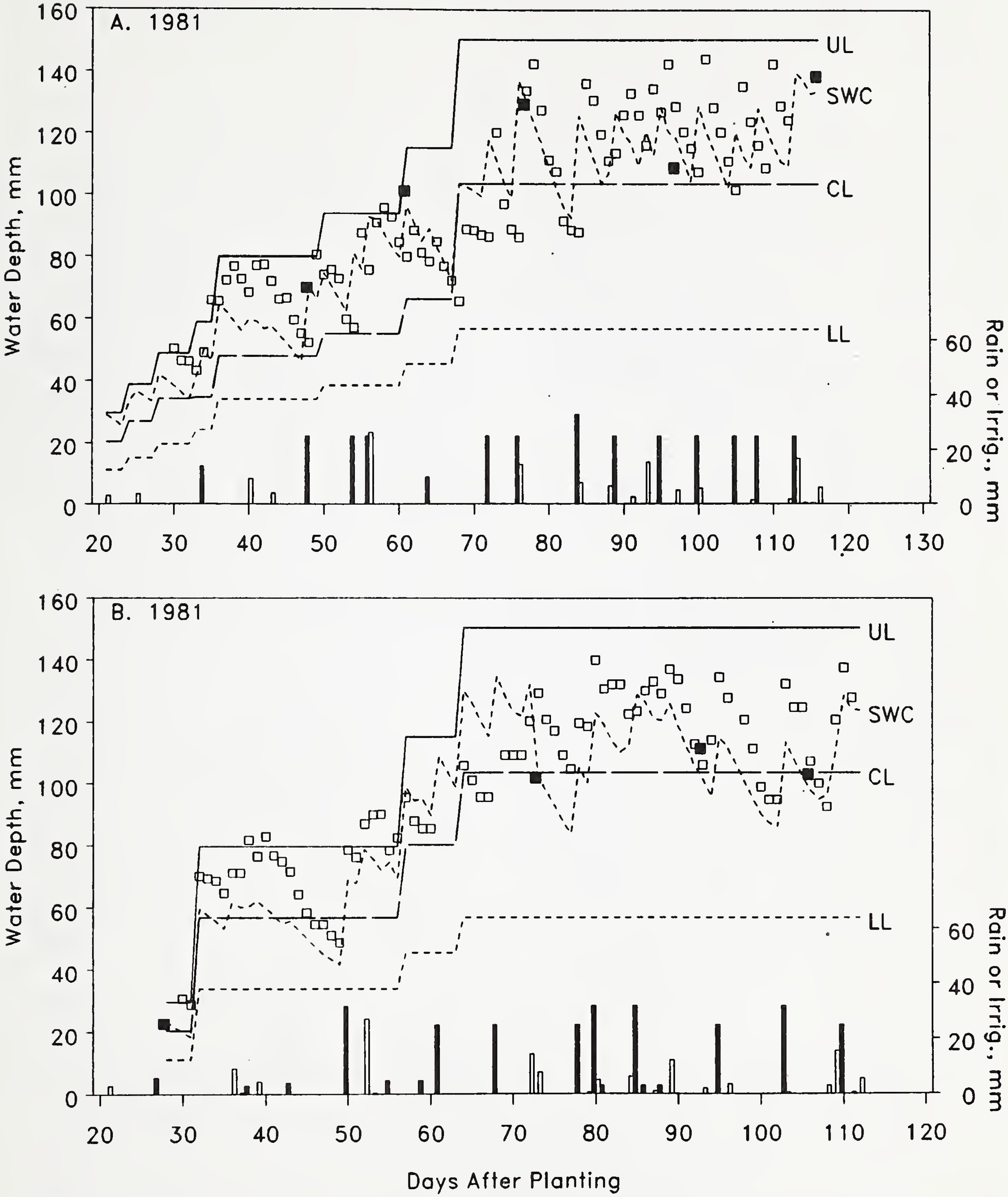

Figure 4.
Daily root-zone water content, irrigation, and rainfall data for (A) B23 treatment and (B) RDC4 treatment in 1981. See figure 1 for explanation of symbols.

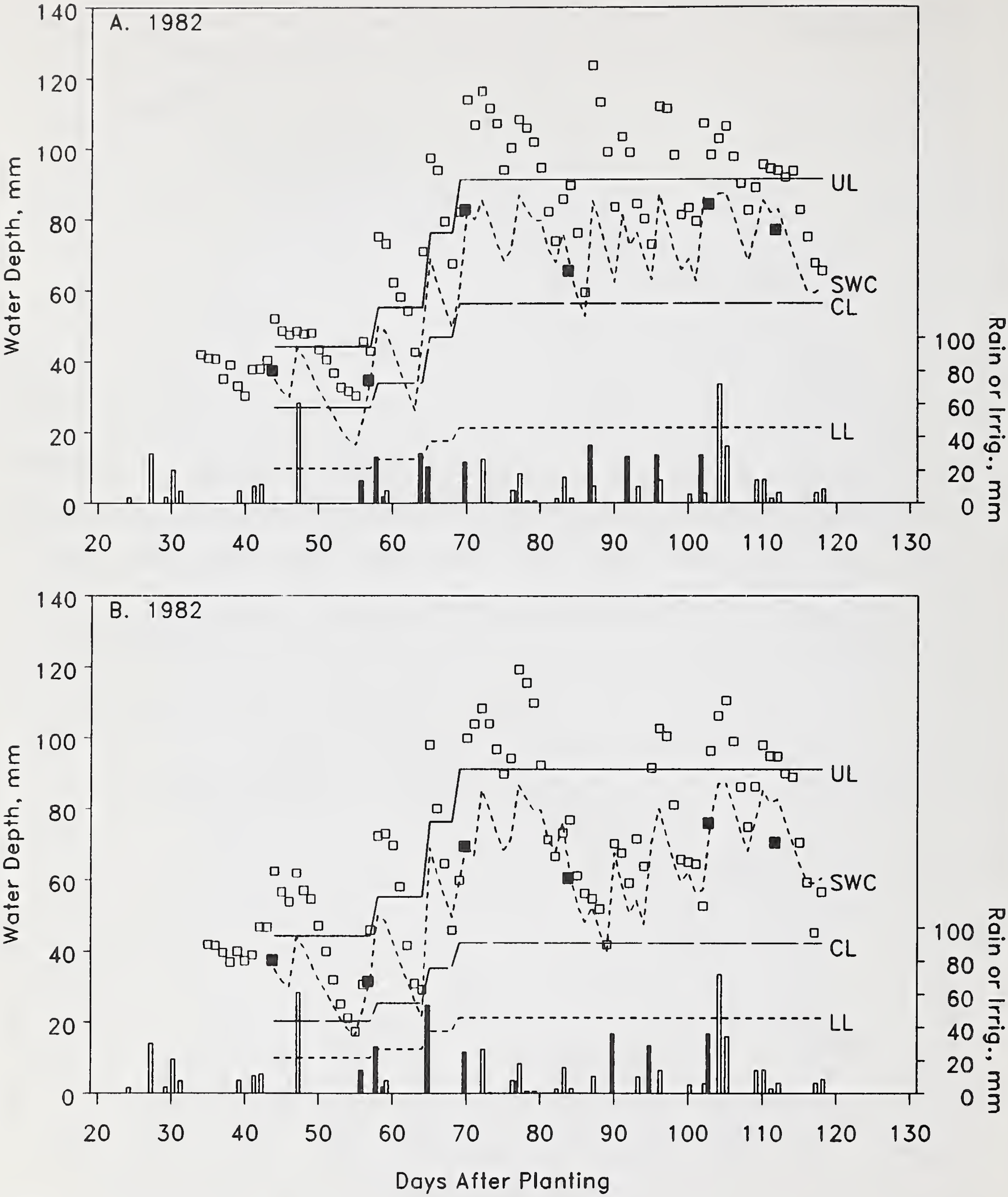

Figure 5.
Daily root-zone water content, irrigation, and rainfall data for (A) GRI1 treatment and (B) GRI2 treatment in 1982. See figure 1 for explanation of symbols.

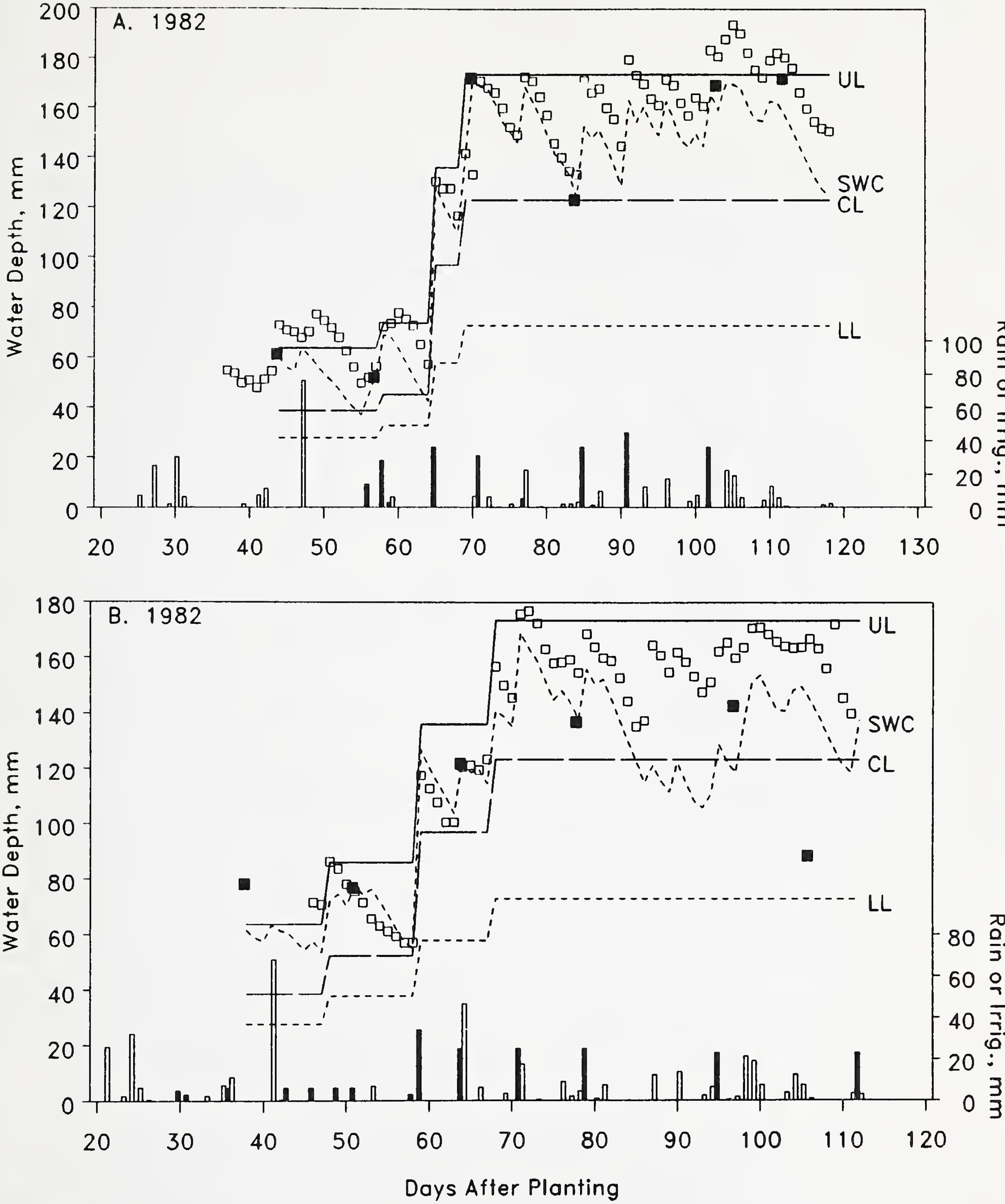

Figure 6.
Daily root-zone water content, irrigation, and rainfall data for (A) B1 treatment and (B) RDC2 treatment in 1982. See figure 1 for explanation of symbols.

Three statistics were computed to help evaluate the differences between GWC and SWC. First, the mean of the differences was calculated by the equation

$$\bar{d} = \frac{d_1 + d_2 + \ldots + d_n}{n}$$

where,

$\bar{d}$ is the mean of the differences;
d_1, d_2, and so forth, are differences between the average GWC (four to six relicate samples per date) and the SWC; and
n is the number of sampling dates.

Both WC values are expressed as millimeters of soil water to the current depth of rooting plus 0.1 m. The mean of the differences indicated the tendency of the CBWB to correct itself over the season. Values of $\bar{d}$ near zero indicated that the positive and negative deviations were equal; however, this statistic revealed nothing about the magnitude of the differences. The second statistic, the mean of the absolute difference ($\bar{a}$) was calculated similarly:

$$\bar{a} = \frac{|d_1| + |d_2| + \ldots + |d_n|}{n}$$

This statistic indicated the average deviation of the SWC from the GWC value on any particular sampling date. The third statistic, the t value, was computed as the mean of the differences, $\bar{d}$, divided by the standard error of the mean differences. Significance of the t value indicates that the null hypothesis— that is, the hypothesis that the mean of differences between SWC and GWC is zero— must be rejected. These three statistics were computed for each of the original CBWB runs for which five or more sampling dates of GWC were available (table 7).

Of the original runs, the magnitude of $\bar{d}$ for the GRG, GRG2, and GRG1 tests on Bonifay soil was greater than the typical irrigation amount. Thus, for any given date, the CBWB could fail to indicate a needed irrigation. With the inputs used in those tests, the CBWB consistently overestimated WC. For the tests on Tifton soil and the 1982 tests on Bonifay soil, SWC and GWC pairs were not significantly different. While $\bar{d}$ for those tests was very low, the $\bar{a}$ indicates predictions on any given sample day generally were greater than $\bar{d}$ indicated. After completing the plotting and analysis of the original CBWB output, each of the above tests was rerun without in-season reinitializations. Running the CBWB without in-season corrections would be desirable from the growers' standpoint. As expected, agreement was worse for most tests as indicated by $\bar{d}$ and $\bar{a}$ (table 7). For the 1982 tests, there was only a slight change in $\bar{d}$ and $\bar{a}$. In 1982 there were many rainfall events which produced excess water (EW). On a day of EW, the CBWB simply discarded the EW and subtracted that day's predicted ET (AETP) from the UL. When this occurred, both on runs with and without reinitialization, the CBWB predicted the same WC on that day. The difference between runs was in the amount of EW. For example, test GRI2 had 147 mm of excess water for the season as originally run, but had 180 mm without reinitialization. Test B1 had 164 mm originally, but only 114 mm in the trial with no reinitialization. Except for 1982, the reinitialization originally used provide more accurate SWC values.

Each of the tests was rerun again, this time with the CBWB reinitialized on all days when soil moisture was measured and not just on the days originally used. Using all measurements to reinitialize, the CBWB significantly improved the prediction for the 1980 GRG and 1981 GRG2 tests, which had the poorest agreement

Table 7.
Mean difference ($\bar{d}$), mean absolute difference ($\bar{a}$), and t-test values for comparison of measured versus predicted water content paired by observed date using original CBWB data and modifications as indicated

Soil	Test	Year	CBWB Run	Statistics $\bar{d}$	$\bar{a}$	t
				----- mm	-----	
Bonifay	GRG	1980	Original	-41	41	-8.31**
			No Reinitialization	-52	52	-7.07**
			All Reinitialized	-21	26	-1.90NS
			1982 Soil Water UL	-2	6	-0.53NS
	GRG2	1981	Original	-24	24	-3.88*
			No Reinitialization	-37	37	-5.63**
			All Reinitialized	-19	20	2.65*
			1982 Soil Water UL	-4	8	-1.15NS
	GRG1	1981	Original	-33	33	-6.02**
			No Reinitialization	-39	39	-4.40**
			All Reinitialized	-31	31	-4.73**
			1982 Soil Water UL	-8	14	-1.21NS
	GRI1	1982	Original	3	7	0.89NS
			No Reinitialization	3	7	0.89NS
			All Reinitialized	3	6	0.89NS
	GRI2	1982	Original	-4	1	-0.92NS
			No Reinitialization	-4	1	-0.92NS
			All Reinitialized	-4	1	-0.92NS
Tifton	B23	1981	Original	-1	8	-0.30NS
			No Reinitialization	-5	10	-0.99NS
			All Reinitialized	0	7	0.07NS
			1982 Soil Water UL	0	7	0.07NS
	RDC4	1981	Original	-2	11	-0.29NS
			No Reinitialization	-12	12	-1.83NS
			All Reinitialized	-2	11	-0.25NS
			1982 Soil Water UL	-1	10	-0.07NS
	B1	1982	Original	12	14	2.18NS
			No Reinitialization	12	14	2.36NS
			All Reinitialized	12	14	2.18NS
	RDC2	1982	Original	-3	19	-0.25NS
			No Reinitialization	-4	19	-0.31NS
			All Reinitialized	-5	22	-0.39NS

* Indicates significance of t test at 0.05 level.
**Indicates significance of t test at 0.01 level.

between SWC and GWC in the original runs (table 7 and fig. 7A, 7B, respectively). However, the additional reinitialization made little difference in the other tests. Tests on the Tifton soil were already in agreement, and since UL values originally supplied for the Bonifay soil in 1982 were reduced, tests on that soil had good agreement in the original run.

Because SWC in the 1982 original runs for the Bonifay soil was more accurate than the SWC's in 1980 and 1981, UL and LL values supplied in 1982 (table 2) were used with the previous years' data. The 1980 and 1981 data were then rerun without in-season reinitialization. For tests GRG, GRG2, and GRG1, the improvement was indicated by sharp decreases of $\bar{d}$ and $\bar{a}$ as well as the t value (table 7). The comparisons of figures 8 versus 2, figures 9 versus 3A, and figures 10 versus 3B, demonstrate how markedly the SWC values improved for GRG, GRG2, and GRG1, respectively, as a result of decreasing the UL to the 1982 values. When the 1982 UL and LL values for the Tifton soil were applied to the 1981 data, small changes occurred on B23 and RDC4 (table 7); but they were already in good agreement. The conclusion from these alternate runs was that, with the appropriate soil water limits, the CBWB can accurately predict soil WC during the growing season. Using additional reinitializations could improve the short-term accuracy; however, it could not overcome the problem of inappropriate soil water limits.

CBWB Sensitivity to Upper and Lower Limits

The sensitivity of the CBWB to changes in UL was apparent as CBWB inputs were changed from the 1979 through 1982 tests. However, there were changes in many parameters over this time. To more accurately assess the effect of changes in UL on SWC, inputs from five growing seasons were used with hypothetical soil water limits (table 8). The unadjusted limits were essentially the 1982 limits used in tests GRI1 and B1 (table 2). The available water between the UL and LL was varied from 80% to 120% of the 1982 values for each layer and added to the LL, which was constant. Bonifay limits were run using the meteorological inputs, irrigation, rooting depths, and GWC of GRG (Bonifay 1980), GRG2 (Bonifay 1981), and GRI2 (Bonifay 1982). Tifton limits were likewise run using inputs of B23 (Tifton 1981) and B1 (Tifton 1982). Results of the runs are presented in table 9.

Trial soil water limits revealed that the Bonifay tests could have been further improved in 1981 and 1982 by using limits 10% below the unadjusted original values (table 9). However, for 1982, decreasing the available water 20% brought about a significant difference between SWC and GWC. Increases to 20% above the unadjusted limits likewise brought about significant differences in 1980 and 1981. The $\bar{a}$ values indicate that the discrepancies between SWC and GWC values did not change greatly for 10% changes in available water for the Bonifay soil.

The Tifton soil had a higher available WC than the Bonifay soil (table 8), and changes in that available WC brought about sharper differences between SWC and GWC values. While a 10% decrease improved the agreement in 1981, a 10% increase was needed in 1982. This discrepancy was of particular concern because a 10% decrease in 1982 created a significant difference. This suggests that other unknown factors were interacting with the limits. Selection of soil water limits based upon a single year's observations would involve considerable risk.

When soil water limits were changed, the CBWB produced changes in two primary values, the excess water (EW) and the soil factor (KS). The soil factor, derived by the empirical formulas of

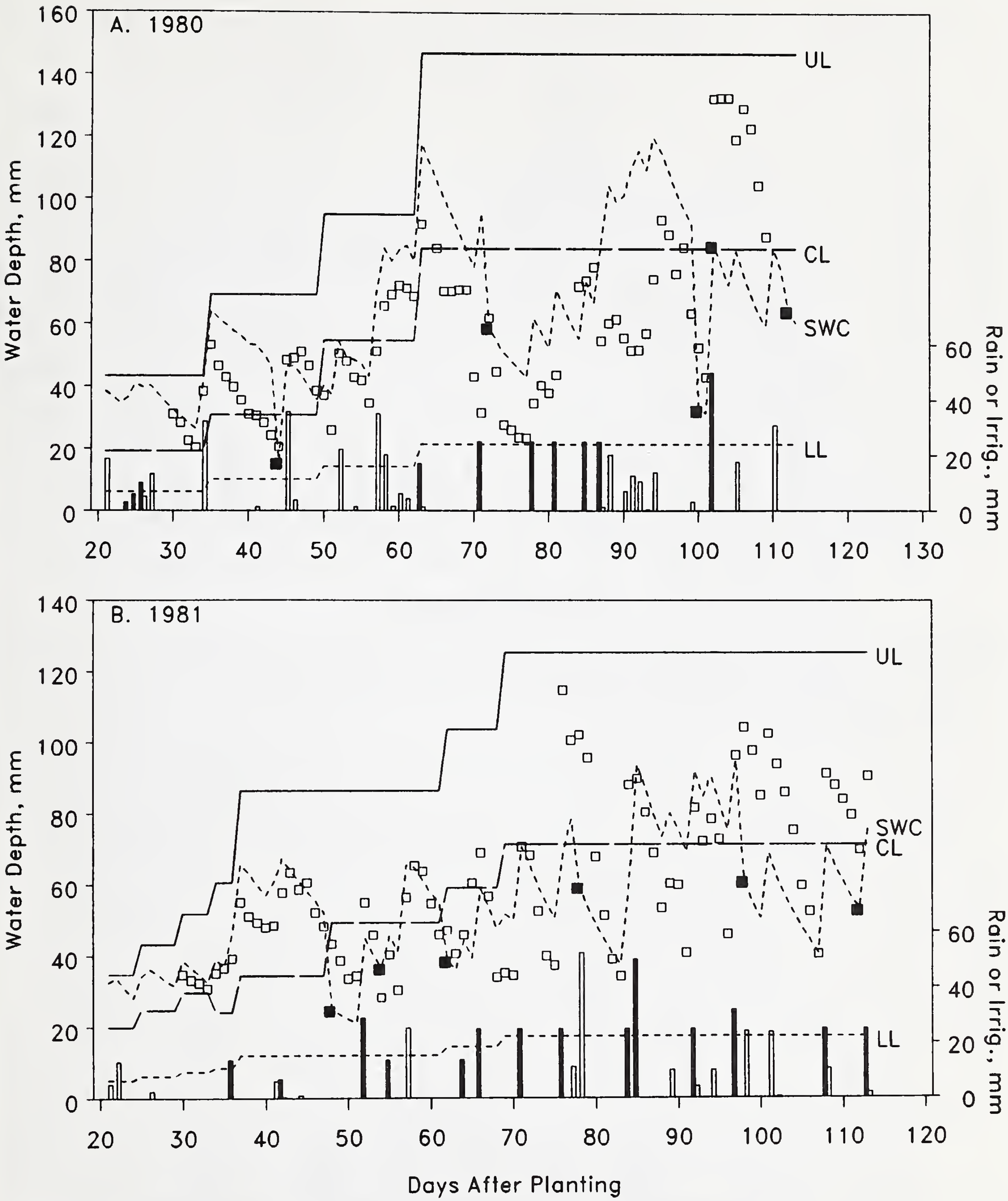

Figure 7.
Daily root-zone water content, irrigation, and rainfall data for (A) 1980 GRG treatment and (B) 1981 GRG2 treatment, both as rerun with additional reinitialization. Curves show the CBWB-based simulated water content (SWC), and the upper limit (UL), critical level (CL), and lower limit (LL) of available water; solid and open bars, respectively, show the amounts of irrigation (Irrig) or rain received; solid squares show the gravimetric water content (GWC). Scale for bars shown on right vertical axis.

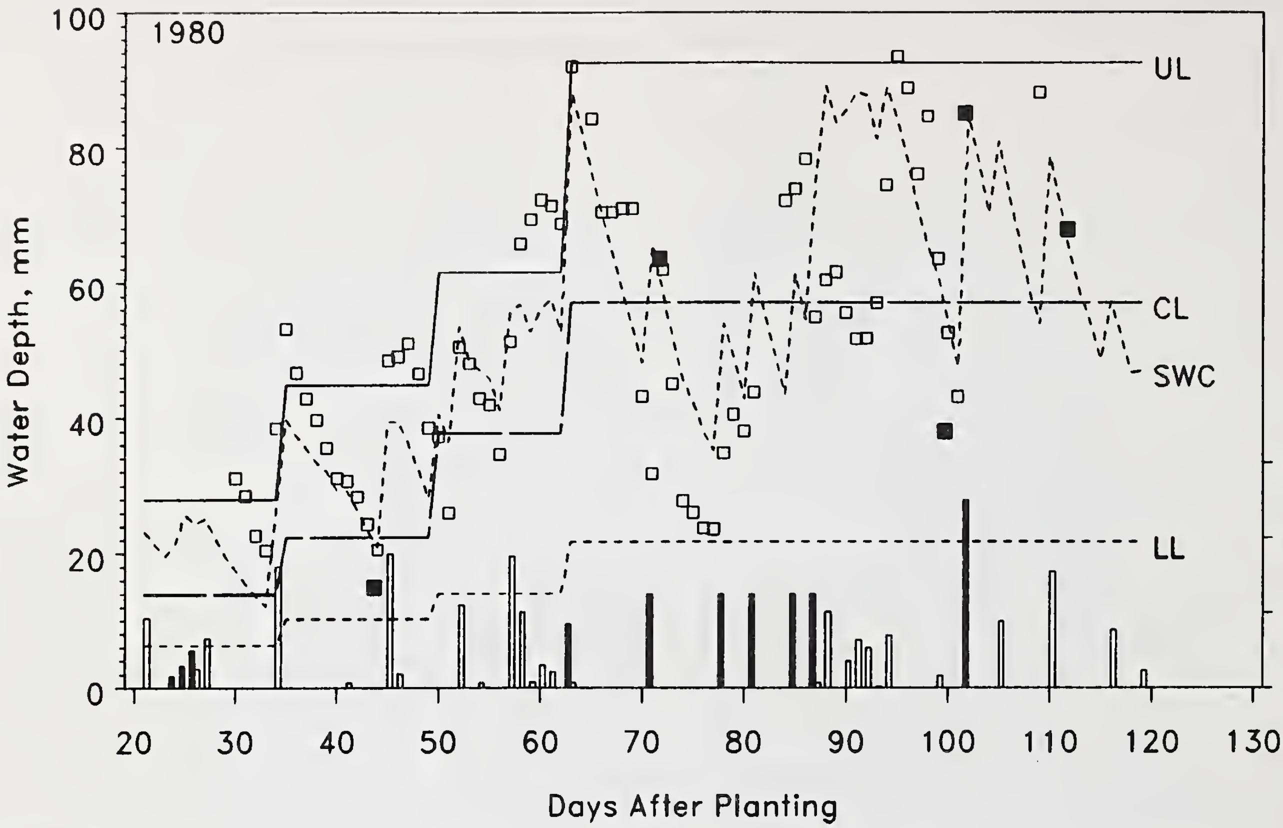

Figure 8.
Daily root-zone water content, irrigation, and rainfall data for 1980 GRG treatment rerun with 1982 UL and LL. See figure 7 for explanation of symbols.

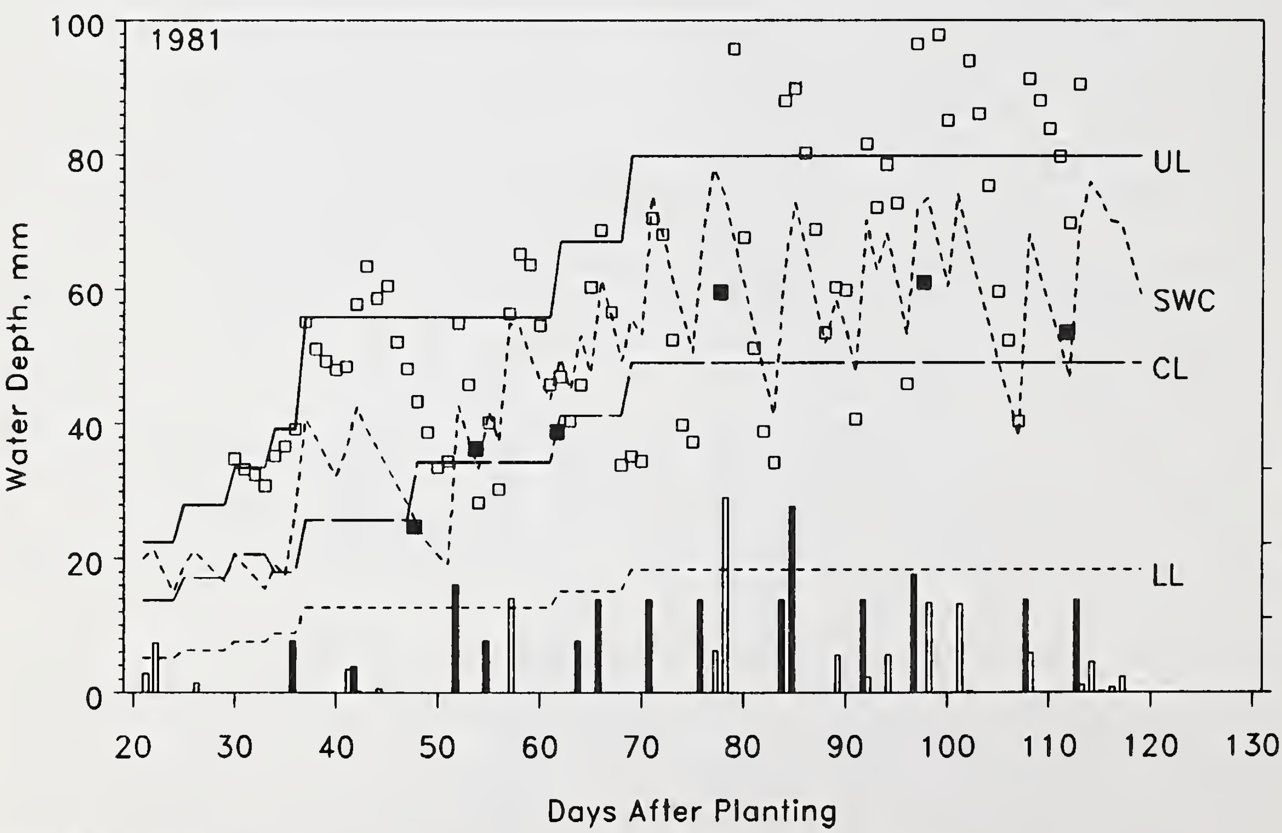

Figure 9.
Daily root-zone water content, irrigation, and rainfall data for 1981 GRG2 treatment rerun with 1982 UL and LL. See figure 7 for explanation of symbols.

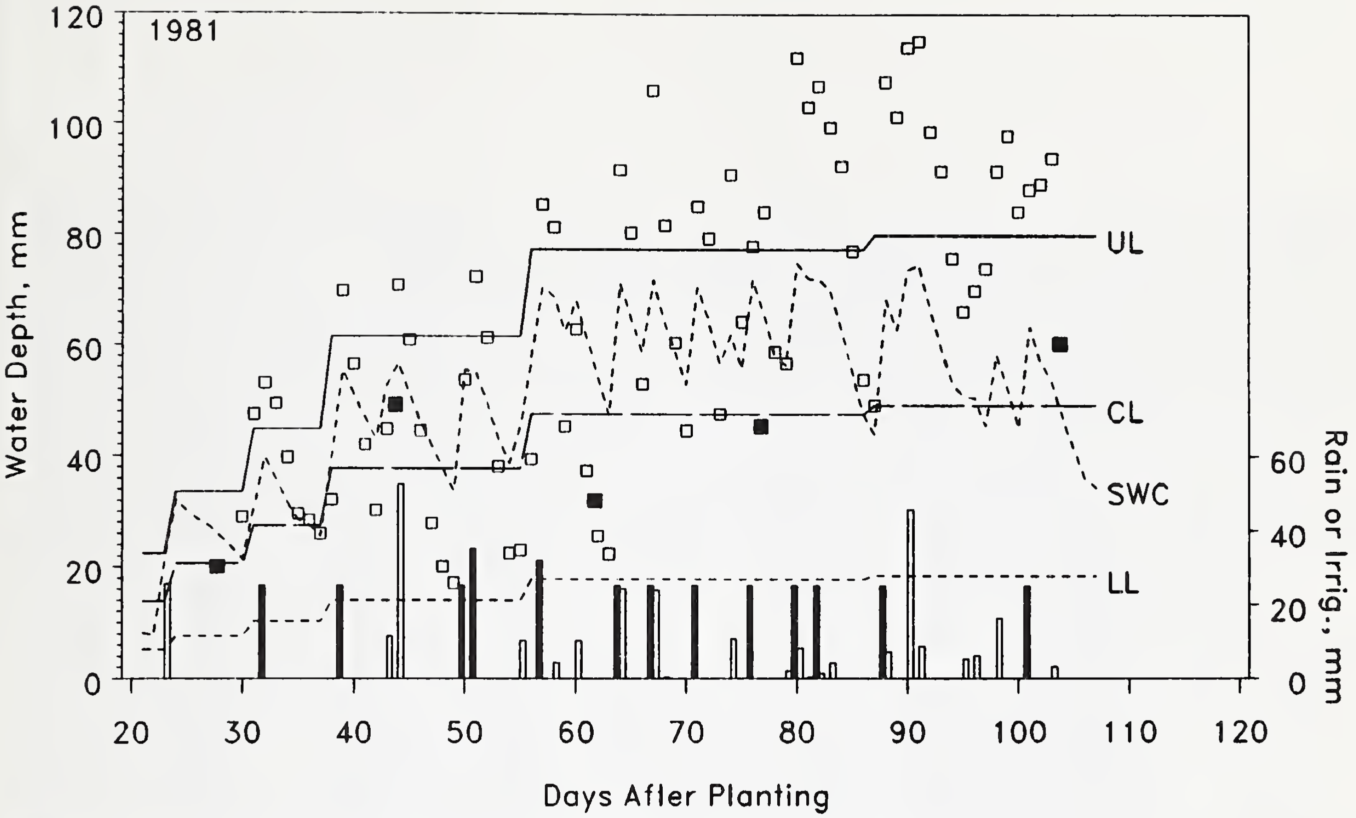

Figure 10.
Daily root-zone water content, irrigation, and rainfall data for 1981 GRG1 treatment rerun with 1982 UL and LL. See figure 7 for explanation of symbols.

Table 8.
Upper (UL) and lower (LL) water content limits of the soil layers used in trial runs to determine sensitivity of CBWB to soil water limits

Soil	Soil Layer From	Soil Layer To	LL	UL -20%	UL -10%	UL Unadjusted	UL +10%	UL +20%
	mm	mm	mm/mm	mm/mm	mm/mm	mm/mm	mm/mm	mm/mm
Bonifay	0	102	.025	.093	.102	.110	.119	.127
	102	152	.025	.093	.102	.110	.119	.127
	152	229	.025	.093	.102	.110	.119	.127
	229	304	.025	.093	.102	.110	.119	.127
	304	457	.025	.093	.102	.110	.119	.127
	457	609	.030	.086	.093	.100	.107	.114
	609	762	.030	.086	.093	.100	.107	.114
	762	914	.030	.086	.093	.100	.107	.114
Tifton	0	102	.053	.139	.149	.160	.171	.181
	102	152	.053	.163	.176	.190	.204	.217
	152	229	.065	.165	.178	.190	.203	.215
	229	304	.065	.165	.178	.190	.203	.215
	304	457	.100	.172	.181	.190	.199	.208
	457	609	.100	.204	.217	.230	.243	.256
	609	762	.100	.220	.235	.250	.265	.280

Table 9.
Mean difference ($\bar{d}$), mean absolute difference ($\bar{a}$) and computed t value for measured versus predicted water content paired by observation date and total season excess water (EW), daily mean soil factor (KS), and daily mean adjusted potential evapotranspiration (AETP) for CBWB runs using various changes in available water

Trial		Available Water	$\bar{d}$	$\bar{a}$	t	EW	KS	AETP
Bonifay	1980	-20%	8.6	10.3	1.96NS	145	.878	4.49
		-10%	3.8	8.5	0.92NS	137	.897	4.58
		Unadjusted	-1.0	6.9	-0.25NS	131	.912	4.65
		+10%	-6.4	6.8	-1.64NS	126	.923	4.71
		+20%	-11.5	11.5	-2.99*	123	.931	4.75
Bonifay	1981	-20%	5.0	5.3	1.85NS	115	.880	4.23
		-10%	0.8	6.3	0.24NS	108	.897	4.31
		Unadjusted	-3.3	7.5	-0.92NS	104	.910	4.36
		+10%	-8.0	9.5	-1.99NS	100	.921	4.40
		+20%	-12.4	12.4	-2.80*	98	.928	4.44
Bonifay	1982	-20%	6.4	6.4	2.87*	206	.902	5.27
		-10%	1.6	4.6	0.54NS	193	.917	5.36
		Unadjusted	-2.9	8.6	-0.74NS	183	.927	5.41
		+10%	-7.7	12.8	-1.53NS	172	.936	5.46
		+20%	-12.2	16.8	-2.00NS	162	.942	5.50
Tifton	1981	-20%	8.3	8.9	2.89*	58	.899	4.57
		-10%	1.2	6.4	.35NS	51	.915	4.64
		Unadjusted	-6.0	7.2	-1.53NS	45	.927	4.70
		+10%	-13.3	13.2	-2.96*	41	.936	4.74
		+20%	-20.4	20.4	-4.00*	39	.941	4.77
Tifton	1982	-20%	22.4	22.4	3.24*	133	.941	5.47
		-10%	14.8	14.8	2.59*	118	.949	5.52
		Unadjusted	7.2	10.1	1.42NS	105	.954	5.54
		+10%	-0.6	8.0	-0.13NS	92	.957	5.56
		+20%	-8.2	11.8	-1.48NS	79	.960	5.58

*Indicates significance of t test at the 0.05 level.

Jensen and Haise (1963), describes the relationship between available soil water and AETP, that is, the effect of limited soil water on plant moisture stress. As soil water limits were increased, there was more space to store rainfall and irrigation, so excess water was decreased (table 9). With the additional water no longer lost as excess, the average SWC was increased; and, consequently, the average soil factor was increased. Since the soil factor was multiplied by the potential evapotranspiration (ETP) to give the actual evapotranspiration (AETP), increases in the soil factor increased AETP. In effect, the CBWB predicted that a soil with higher available water would lose more water to evapotranspiration over the course of the season.

For trial soil water limits, a 20% increase in UL above the unadjusted value brought about increases of 0.7 to 2.2% in

the daily average AETP (table 9). Since these differences accumulate, it can be expected that the total error, or difference between SWC and actual soil WC, would grow daily by an amount equal to about 1.5% of the daily AETP. That amount plus the changes in EW was enough, in the trial runs, to produce significant errors in 1980 and 1981 on both soils when the 20% higher UL was used. By comparison, for original runs of GRG, GRG2, and GRG1, the available soil water (table 2) was 113% greater than the available soil water which resulted in the best fit of SWC and GWC (table 9). It should be noted that, for any year, a UL could be assigned for which no excess water is produced. In this case, UL greater than that would have identical daily soil factors; thus, no further changes in agreement between SWC and observed WC would occur. Those limits, of course, may be unreasonable; however, it demonstrates that while 20% increases brought about significant differences in the SWC versus GWC for the trial runs, 50, 75, or 100% increases would not necessarily make the differences greater.

Predicted Versus Tensiometer Estimates of Water Content

The tensiometers placed in the CBWB plots provided a daily check of soil moisture throughout the root zone (that is, indicated zones in the profile where soil water was being extracted) and provided values that were used to estimate WC (TWC) of the root zone each day. For most of the tests on the Tifton soil (figs. 1B, 4A, 4B, 6A, 6B), there was good agreement between the SWC and TWC. When the root zone was confined to the topsoil, usually until about 60 days after planting, the SWC generally was lower than TWC. During that time, rates of withdrawal indicated by the TWC curves were greater than predicted rates.

Later in the growing season, predicted rates of withdrawal agreed with those of the TWC curves. The TWC was considerably higher than the SWC for RDC2 (fig. 6B) after 84 days from planting. Part of this was due to lower withdrawal indicated by TWC throughout the period and, in part, to the TWC response to rainfall on day 87. Inasmuch as each day's tensiometer readings are independent, a single faulty tensiometer reading or faulty tensiometer response would appear as a spike or dip in TWC when plotted. Since the tensiometer readings for days 88 and 89 agree with the increase on day 87, it seems more likely that the rainfall measured on day 87 did not represent what occurred in the field itself. The rainfall amount entered into the CBWB for RDC2 thus was probably low. The TWC for days around 106 suggests that there was an error in GWC for that day. None of the previous trials of the CBWB brought agreement between SWC and that day's GWC. For the Tifton soil, tensiometer observations confirmed that SWC values were reasonable, although the predicted rates of water withdrawal may be too low early in the season.

For the Bonifay soil, tensiometers provided additional insight into the possible sources of error in the CBWB. Throughout the tests, the range of TWC was greater than the range of SWC (figs. 1A, 2, 3A, 3B, 5A, 5B). For the 1979 test GRKM (fig. 1A), the TWC values were greater than the UL imposed on the CBWB. While TWC responded to rainfall and irrigation, SWC lost part of this water as excess. The results of that test suggested that the UL should be increased. The field-observed drained UL was used for this reason for the 1980 and 1981 tests.

The increased UL for the 1980 and 1981 tests on Bonifay soil led to generally poor agreement of TWC and SWC (fig. 2, 3A, 3B). As pointed out earlier, the CBWB had considerably overestimated SWC at the time of each GWC. The TWC curves indicate how often SWC was below the

desirable CL. The TWC decreased more rapidly than SWC during drydown throughout the season for this soil. However, the effective increase in TWC following rainfall or irrigation was greater than the increase in SWC. As a result, SWC agreed more closely with TWC following rewetting than following drydown. Since soil water samples were typically taken after some drydown, the disagreement between GWC and SWC was greatest at the time of sampling.

In 1982 (fig. 5A, 5B), the UL for the soil was decreased. While this forced the SWC into closer agreement with GWC data (which in this year were often taken after rainfall), the decreased UL prevented SWC from reaching the values indicated by TWC. As in previous years, the rate of withdrawal indicated by the TWC curves was greater than predicted. The effect of decreasing available water was to decrease the average daily AETP (table 9). The daily withdrawal should equal the AETP. Therefore, decreasing the UL was contrary to improving the agreement between withdrawal rates. It was, instead, an artificial means of improving the CBWB's prediction near the LL.

Disagreement between SWC and TWC may have several causes. First, TWC values are calculated values subject to systematic errors if the moisture release curves are not accurate. Second, TWC values are subject to somewhat random errors because hysteresis effects are not considered. Third, the CBWB's soil factor adjustment is dependent upon the limits chosen. The method of computation used for soil factors may not be as appropriate for deep sands as for other soils. Fourth, the rate of withdrawal includes drainage as well as evapotranspiration. The CBWB, as used in these studies, assumes all drainage and distribution occur immediately following rainfall or irrigation. Although all of these causes of disagreement probably occur to some extent, it was not possible in this study to clearly separate them.

Crop Factors

In addition to the adjustment of ETP for soil moisture, the CBWB uses two equations to adjust ETP for plant growth stage. One equation is used for the first two-thirds of the growing season, the other for the remainder. Both calculate the crop factor based upon days after planting and days to maturity, as supplied by the user. For all of the early planted tests, corn with maturities of 105 or 110 days was used. Crop factors for these two are shown as the solid lines in figure 11. Vertical lines indicate the actual days following planting when pollination occurred for the 11 tests. The maximum value for the crop factor should occur around the time of pollination. The crop factors actually used were late by 8 to 16 days. Using an 85-days-to-maturity value brought the maximum crop factor in line with the time of actual pollination; however, the rate of decrease in the crop factor value during grain fill probably was too great. Proper adjustment of crop factors will require other equations, perhaps using growing degree days (GDD) to improve the estimate of the time of peak water use.

SUMMARY AND CONCLUSIONS

The CBWB irrigation scheduling technique was tested on corn grown in the Coastal Plain region of Georgia over 4 years on two soil types. The CBWB, which utilized crop data, soils data, and both meteorological observations and forecasted weather, called for irrigation frequently enough in each of nine field trials so that corn yields were equivalent to those produced when irrigation was scheduled by TENS. Grain yields of irrigated corn ranged from 8.4 to 13.4 Mg/ha over all

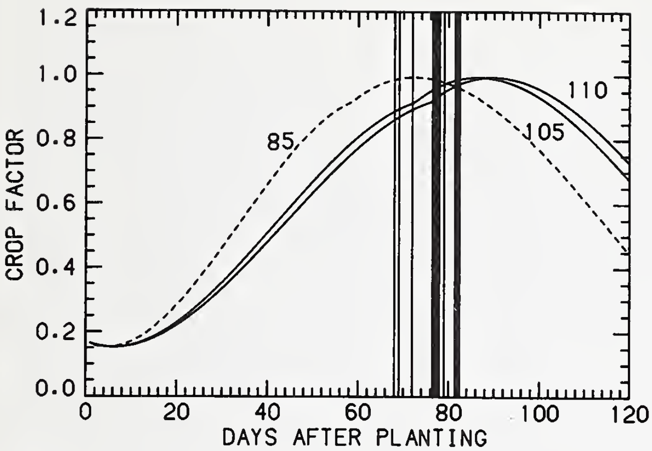

Figure 11.
Crop factors predicted for corn maturing in 85, 105, and 110 days, as shown with actual date of midpollination (vertical lines) for 11 tests of March- and April-planted corn.

tests. In most instances, the CBWB required more water over the growing season than TENS.

To gain experience with various CBWB inputs and to explore the limits of the CBWB, extensive comparisons of gravimetric measurements of soil water and of tensiometer estimates of soil water content with predicted soil water content were made. For the Tifton loamy sand, eight field tests confirmed that the CBWB could reasonably predict the total soil WC of the root zone. The CBWB tended to underestimate daily water use or water removal from the root zone during the first 60 days after planting.

For the Bonifay soil, the CBWB was not able to accurately predict WC over the full range of soil WC. When the CBWB agreed with observed WC in moist soil, it seriously overestimated the WC when that soil dried down. Conversely, when available water limits were lowered, the CBWB could predict WC of drier soil but not of moist soil. Because correct prediction in the drier range is more important for irrigation scheduling, a careful selection of available water limits is needed for deep sands to prevent crop water stress. For this soil, the CBWB underestimated daily water removal from the soil throughout the growing season.

A sensitivity analysis of the UL indicated that by increasing the limit of available water 20%, the CBWB predicted about a 1.5% increase in daily actual ET. Yet in 1980 and in 1981, when the available WC was increased more than 100%, the CBWB still predicted a lower actual ET or lower withdrawal rate than actually occurred. Further refinements in calculation of the soil factor will be necessary so that correct UL and LL can be confidently supplied to the CBWB. An examination of the crop factor indicated that some improvements in predicted ET could be made by adjusting the equations for that factor so that peak values of crop factors occur at the time of pollination rather than later.

The CBWB was an effective irrigation scheduling technique for south Georgia even though uncertainties exist over how to set input limits. There is sufficient flexibility in adjusting rooting depth and allowable depletion to improve in-season operation of the CBWB. However, improvements in water use efficiency will require refinements in computations of crop and soil factors.

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8. GAINESVILLE, FLORIDA

L.C. Hammond and J.M. Bennett[1]

INTRODUCTION

In Florida, because of inconsistent and often unfavorable rainfall distribution patterns coupled with sandy soils of low water and plant nutrient storage capacities, irrigation and multiple fertilizer applications during the season are needed for efficient crop production. Reasonably successful irrigation and other management practices have evolved over the years from farmer experience and scientific findings. Nevertheless, recent population growth has accelerated the demand on Florida's large, but finite, water resource and has made it necessary that all users -- agriculture, municipalities, and industry -- develop more efficient water-use systems.

In most of the humid Southeastern United States, crop-yield-limiting droughts are common. Irrigated acreage in 11 Southeastern States increased by 20% in the 3-year period 1975-1978 (Bruce et al. 1980). Droughts in this area are a consequence not only of uneven rainfall distribution but of soils with low water storage capacity and physical and chemical properties which frequently limit the rooting volume. Irrigation timing, application intensity, and amount per application each affect the fraction of added water used by the plant, the leaching losses of pesticides and plant nutrients, and, in many cases, the degree of aeration in the root zone. Application of these factors to irrigation management in humid regions has been addressed by the development of water management systems based on high-frequency irrigation with shallow wetting of the root zone (Rawlins and Raats 1975, Phene and Beale 1976, Miller and Aardstad 1976). In these systems, the key objective is to leave room in the root zone, at each irrigation, for rainfall which may follow (Fischbach and Somerhalder 1974, Hammond et al. 1981, Jones et al. 1984).

A high irrigation-use efficiency in crop production cannot be achieved without some knowledge of the relationship between yield and transpiration. Transpiration (seasonal) is difficult to measure, but it has been shown that crop yields increase linearly with actual evapotranspiration (AET) until potential evapotranspiration (PET) has been attained (deWit 1958, Hanks 1974, Skogerboe et al. 1979, Tanner 1981). Furthermore, a linear relationship often exists between yield and seasonal irrigation. The mathematical expressions of these yield/water-use relationships, or crop-water production functions, are useful for irrigation system design and for evaluating and improving irrigation management strategies (Stegman et al. 1980). The ratio of the slopes of the two production functions (irrigation:AET) is a measure of the efficiency of irrigation use for the specific crop season (Hammond et al. 1981).

Objectives of these studies included, in addition to evaluating irrigation scheduling methods, the development and evaluation of water management strategies using crop-water production functions and the evaluation of the response of corn hybrids to water stress and to enhancement of the root zone by physical modification of the soil profile.

MATERIAL AND METHODS

Irrigation scheduling experiments on corn were conducted from 1979 to 1981 on a one-half-hectare site at Gainesville, FL. The soil was primarily Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudult), with the argillic layer present at depths greater than 1.65 m. In about one-fourth of the plot area, the argillic layer was present at

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depths greater than 2 m (Lake fine sand, coated, hyperthermic, Typic Quyartzipsamment). The soil had been used for numerous experiments over a period of more than 30 years. Management of small plots over the last 5 years had created considerable spatial variability in terms of fertility, plowpan development, and nematode infestation. Soil water and bulk density characteristics at the site are given in tables 1 and 2.

Twenty-four water management plots (six treatments with four replications) were established, along with the installation of a permanent system of overhead impact sprinklers capable of delivering water at 25 mm/h simultaneously to all replicates of a given treatment. Each plot was 13.7 m x 13.7 m in size, with one-quarter-circle sprinklers located on risers at each corner of the plot. Sprinkler delivery radius was approximately 14.5 m at a nozzle pressure of 380 kPa.

Water management treatments comprised the main plots, and corn hybrids comprised the subplots or subsubplots. In 1981, the 24-plot area was subdivided into two 12-plot experiments. One of these experiments included nonsubsoiled and subsoiled treatments as subplots, and corn hybrids as subsubplots. Subsoiling consisted of opening and backfilling trenches 0.6 m on center. Trenches, 0.1-m wide by 0.5- to 0.6-m deep, were dug with a motorized trencher and backfilled by hand to within 0.15 m of the surface with a soil-sawdust mixture (approximately 3:1 by volume). Soil alone, from the trenching spoil, was used to backfill the remainder of the trench.

Seedbeds were prepared about 2 weeks before planting each year by turning the land with a three-bottom moldboard plow and disc harrowing to incorporate broadcast fertilizer and nematicide (table 3).

Table 1.
Soil water characteristic (desorption) data for various layers of Arredondo fine sand, Gainesville, Florida

Soil water pressure*	Water content, volume fraction				
	0-0.15**	0.15-0.30	0.3-0.6	0.6-1.5	1.5-1.8
kPa	m^3/m^3				
0.4	0.322	0.322	0.329	0.353	0.366
3	0.235	0.241	0.241	0.236	0.245
6	0.099	0.099	0.103	0.101	0.116
8	0.078	0.078	0.078	0.073	0.092
10	0.068	0.068	0.067	0.062	0.082
15	0.055	0.055	0.054	0.050	0.070
20	0.051	0.051	0.051	0.046	0.066
35	0.043	0.043	0.044	0.038	0.060
1500	0.019	0.019	0.021	0.020	0.035

* Negative sign omitted.
**Depth of soil layers (m).

Table 2.
Field profile water content and bulk density, Arredondo fine sand, Gainesville

Depth	Bulk density	Water content, volume fraction*	
		Upper limit(UL)	Lower limit(LL)
m	Mg/m^3	-------- m^3/m^3	--------
0-0.15	1.53	0.120	0.030
0.15-0.30	1.67	0.100	0.030
0.30-0.60	1.57	0.080	0.030
0.60-1.50	1.57	0.080	0.030
1.50-1.80	1.53	0.085	0.020

* Limits of available soil water content as determined in the field and as used subsequently in the computer-based water balance model.

Table 3.
Management data for corn, 1979-1981, Gainesville

Year	Row width	Plant population	Fertilizer		Herbicide**	Nematicide***
			Preplant*	Sidedress		
	m	pl/ha	kg/ha	kg/ha	L/ha	kg/ha
1979	0.9	71,000	(45-39-149)	155	4.7	56
1980	0.6	71,600	(73-0-222)	235	4.7	22
1981	0.6	80,700	(0-44-198)	350	4.7	56

* Amounts of N-P-K. In 1981, the fertilizer contained, in addition, Mg, B, Mn, and Zn in the respective quantities: 60, 2.6, 7.8, and 7.8 kg/ha.
** Lasso in 1979 and 1981; Sutan - atrazine each in amount shown in 1980.
***Furadan 15G in 1979 and 1981; Counter 15G in 1980.

Most of the nitrogen fertilizer was applied in two to four sidedressings of NH_4NO_3 during the period from 30 to 65 days after planting. Corn seed were hand planted at the desired population with dibble planters. Herbicide was then sprayed over the soil surface and the surface wetted with about 8 mm of irrigation water. A single cultivation usually provided adequate weed control. Recommended insect control procedures were used as needed for budworm and earworm. Plant populations and corn hybrids used in the study are shown in tables 3 and 4, respectively.

Corn was harvested within 10 days after black layer maturity. Grain yields (15.5% moisture) were calculated from unshelled weights, assuming a shelling percentage of 80. Other plant parameters were not measured consistently and will not be reported here. Growing season dates and seasonal water data are given in table 5.

Table 4.
Corn hybrids used in the water management studies at Gainesville, 1979-1981

Year	Brand	Hybrid*
1979	Funk	G4507
1980	Pioneer	3160
	Funk	G4507
1981	Pioneer	3369A
	Pioneer	3160
	DeKalb	XL-71
	Funk	G4507

* Hybrids were subplots of water management treatments in 1980 and sub-subplots of subsoil treatments in 1981.

Water management treatments are shown in table 6. These treatments, along with seasonal rainfall distribution differences, produced a fairly broad range of plant water stress levels, as indicated by the resulting seasonal amounts of irrigation and simulated actual evapotranspiration (AET). Irrigation was usually applied near daybreak, when wind was not a problem. The basic strategy throughout the studies was to irrigate frequently but incompletely by refilling only a part of the water-depleted soil profile, thus leaving some capacity for storing rainfall which might be received shortly after irrigation.

Contrasting irrigation treatment schedules were established through variations in amounts of irrigation (light or medium), timing methods (tensiometer or model), and seasonal schedule (before or after tasseling). Timing methods and criteria were as follows: (1) tensiometer (TENS), irrigate on the day when early-morning tensiometer readings at the 0.15-m depth indicate soil water pressure (SWP) values in the -20- to -40-kPa range, and (2) model (computer based water balance, CBWB), irrigate on the day after the simulated soil water content (SWC) in the root zone falls below the established critical level (CL). On numerous occasions, the timing criteria were not strictly followed because of weather conditions and forecasts, observed plant wilting, scheduling inconveniences (such as weekends), and lateness of season.

Soil water content (WC) was monitored three ways: by periodic gravimetric analysis, by weekly analysis using the neutron method (Troxler model 1255 neutron probe and model 2651 scaler-ratemeter, along with a calibration curve for well-drained sandy soils of the Gainesville area), and by SWP readings obtained with tensiometers placed at 0.15-m depth intervals to at least the 0.9-m depth.

Table 5.
Growing season dates, seasonal rainfall, and pan evaporation for 3 corn-growing seasons, Gainesville

Year	Growing season dates*				Rainfall	Pan Evaporation
	Planting	Emergence**	Tasseling	Maturity***		
					----------mm----------	
1979	3/13	3/22	5/19	7/8	408	584
1980	2/28	3/98	5/14	7/7	360	644
1981	3/10	3/22	5/17	7/12	241	676

* Season lengths for water measurements were 104, 120, and 106 days, respectively, for 1979, 1980, and 1981.
** Date at approximately 50% emergence.
***Maturity, as indicated by black layer, varied slightly among corn hybrids.

The CBWB model has been described in chapter 2. Daily water balance computations were made for all water management treatments in the Florida study, except the subsoiled subplot treatments in 1981. Complete local weather data were obtained from a U.S. Weather Bureau station located approximately 350 m from the experimental plots. Soil water capacity values used in the Florida study (table 2) were based on field measurements and were slightly higher than expected from the water characteristic data of table 1. Allowable depletions (table 7) and rooting depths (table 8) varied slightly with season, reflecting adjustments made from field observations and measurements.

RESULTS AND DISCUSSION

During the three-season study at Gainesville, there was a total of 14 different water management regimes in terms of total seasonal water input (tables 5, 6). In 1981, treatment 1 and the nonsubsoiled subplot of treatment 4 were duplicate rainfed treatments. Each of the 14 regimes was subjected to analysis with the CBWB model (chapter 2). Subsoiled subplots in the 1981 experiment (treatments 4, 5, 6) were not included in these analyses. The results are presented in figures 1 through 7. Treatment 5 in 1981 (nonsubsoiled subplot) was not included with the figures, since it was an approximate duplicate of treatment 3.

Data in these figures include measured daily rainfall and irrigation (bar graphs) as well as periodically measured soil WC in an estimated time-dependent root zone (table 8). Measured WC is designated by open and filled squares for neutron and gravimetric methods, respectively. Four curves show daily predicted root zone water contents (in units of depth). Two of these curves, the upper (UL) and lower limits (LL) of plant available water, result from the measured water contents in table 2 and the estimated root depths in table 8. The line labeled "SWC" shows the soil water content predicted by the CBWB

Table 6.
Water management treatments used for corn during 1979-1981 and simulated seasonal water balance, Gainesville

Treat. no.	Irrigation* Strategy**	Number	Amount	Efficiency***	AET+	Drainage
			mm		mm	mm
1979						
1	None, rainfed	0	0	-	331	168
2	Irrig., light, TENS	9	144	0.8	446	181
3	Irrig., medium, TENS	9	203	0.6	454	228
4	Irrig., light, TENS, began at tasseling	7	125	0.9	441	168
5	Irrig., light, TENS, ending at tasseling	2	21	0.2	336	184
1980						
1	None, rainfed	0	0	-	333	110
2	Irrig., light, TENS	11	176	0.8	475	134
3	Irrig., light, CBWB	11	186	0.8	477	136
4	Irrig., light TENS, began at tasseling	7	132	0.9	449	120
1981						
1	None, rainfed	0	0	-	299	39
2	Irrig., medium, CBWB	14	238	0.8	483	73
3	Irrig., light, CBWB	14	218	0.8	482	54
4	None, rainfed	0	0	-	299	39
5	Irrig., light, CBWB	15	238	0.8	485	54
6	Irrig., light, CBWB began at tasseling	8	146	0.8	415	39

* Seasonal rainfall amounts are given in table 5.
** Irrigation timing: TENS - tensiometer (-20 kPa at 0.15-m depth); CBWB - model (simulated SWC below CL).
***Defined as the increase in seasonal AET per unit of seasonal irrigation.
\+ Simulated actual evapotranspiration.
Simulated drainage from crop root zone; CBWB drains excess over UL on day excess occurs and before subtraction of daily AET from stored water.
Treatments 1, 2, and 3 = experiment 1; 4, 5, and 6 = experiment 2, split plots (nonsubsoiled and subsoiled).

Table 7.
Allowable depletion of available water capacity for 3 seasons, Gainesville

Days after planting*	Allowable depletion**		
	1979	1980	1981
	------------%	---------------	
10	-	75	-
12	-	75	75
14	80	75	75
17	75	75	75
22	70	70	75
25	65	65	70
27	60	60	65
30	60	60	60
49	50	60	60
104	60	60	60

* Days listed are those needed to show the allowable depletions for all 3 seasons in a single table.
**Percentage of available water depleted, rather than level of depletion.

model. Triangles on this curve identify the days when the SWC was less than CL (calculated from allowable depletion values in table 7 and the plant available water content in the root zone).

Rainfall and Irrigation

Bar graphs of rainfall and irrigation (figs. 1-7) reveal the times and frequencies of droughts and the various irrigation scheduling responses to those droughts. Each season contained one or more long droughts, the longest being in 1981, when seasonal rainfall was lowest (table 5). Droughts were experienced during late midseason in 1979, midseason and the late season in 1980, and early season and midseason in 1981.

Seasonal irrigation amounts and number of events (table 6) increased with decreasing seasonal rainfall, 1979 through 1981. Within seasons, treatments were different in terms of timing, frequency, and amount per irrigation event, as well as total seasonal events and quantities.

Irrigation Timing

Although irrigations were not always scheduled in accord with timing criteria established at the outset, it is still possible to compare and evaluate the TENS and CBWB methods of timing irrigations, in terms of the status of these two indicators of soil WC both at actual times of irrigation and at times when no irrigation was scheduled despite signals of need.

In the 3-year study, there were 86 irrigation events when tensiometer readings were collected just prior to irrigation. These soil water pressure (SWP) data at all depths are given in tables 9, 10, and 11. In evaluating the TENS method, a

Table 8.
Corn root depth with time as used in the computer-based water balance model, 1979-1981, Gainesville

Days after planting*	Root depth 1979	1980	1981	Days after planting	Root depth 1979	1980	1981	Days after planting	Root depth 1979	1980	1981
	--------m-------				--------m-------				--------m-------		
10	0.08	0.08	-	43	0.60	0.60	0.53	67	1.18	1.18	1.38
11	0.10	0.10	0.18	44	0.66	0.63	0.55	68	1.18	1.18	1.40
13	0.13	0.13	0.18	45	0.65	0.65	0.58	69	1.20	1.20	1.43
16	0.15	0.15	0.18	46	0.68	0.68	0.60	70	1.20	1.20	1.45
18	0.18	0.18	0.18	47	0.70	0.70	0.63	71	1.23	1.23	1.48
20	0.20	0.20	0.18	48	0.73	0.73	0.65	73	1.25	1.25	1.50
22	0.23	0.23	0.18	49	0.75	0.75	0.68	74	1.28	1.28	1.50
23	0.23	0.23	0.20	50	0.78	0.78	0.70	75	1.28	1.30	1.53
25	0.25	0.25	0.23	51	0.80	0.80	0.73	76	1.30	1.30	1.53
27	0.28	0.28	0.23	52	0.83	0.83	0.75	77	1.30	1.33	1.55
28	0.28	0.28	0.25	53	0.85	0.85	0.78	78	1.33	1.33	1.55
29	0.30	0.30	0.25	54	0.88	0.88	0.80	80	1.35	1.35	1.58
30	0.33	0.33	0.28	55	0.90	0.90	0.88	83	1.35	1.35	1.60
31	0.35	0.35	0.28	56	0.93	0.93	0.95	85	1.38	1.38	1.60
32	0.35	0.35	0.30	57	0.95	0.95	1.03	86	1.38	1.38	1.63
33	0.38	0.38	0.33	58	0.98	0.98	1.10	88	1.40	1.40	1.63
34	0.40	0.40	0.35	59	1.00	1.00	1.15	89	1.40	1.40	1.65
36	0.43	0.43	0.38	60	1.03	1.03	1.20	93	1.40	1.40	1.68
37	0.45	0.45	0.40	61	1.05	1.05	1.25	97	1.45	1.40	1.68
38	0.48	0.48	0.40	62	1.08	1.08	1.28	100	1.48	1.40	1.68
39	0.50	0.50	0.43	63	1.10	1.10	1.30	103	1.50	1.40	1.68
40	0.53	0.53	0.45	64	1.13	1.13	1.30	107	1.53	1.40	1.68
41	0.55	0.55	0.48	65	1.15	1.15	1.33	111+	1.55	1.40	1.68
42	0.58	0.58	0.50	66	1.15	1.15	1.35				

*Days have been omitted for all 3 years where there was no change from the previous date.

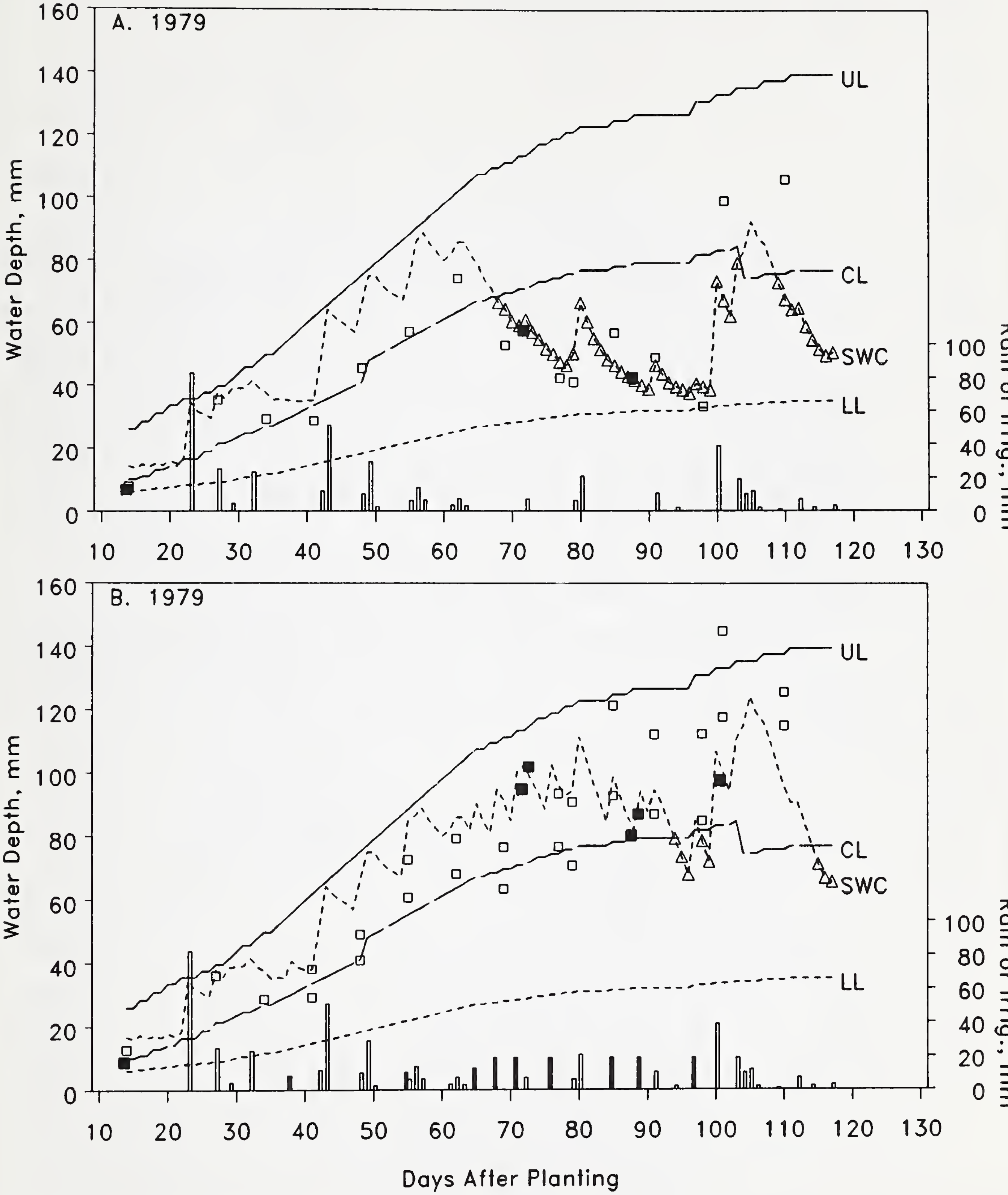

Figure 1.
Daily root-zone water content, irrigation, and rainfall data for (A) rainfed treatment 1 and (B) irrigated treatment 2 at Gainesville in 1979. Curves show the simulateld water content (SWC) and the upper limit (UL), critical level (CL), and lower limit (LL) of available water; solid and open bars show the amounts of irrigation (Irrig) and rain received; triangles flag days when CBWB indicated the need for irrigation; and solid and open squares show measured water contents as determined gravimetrically and with a neutron probe. Scale for bars shown on right vertical axis.

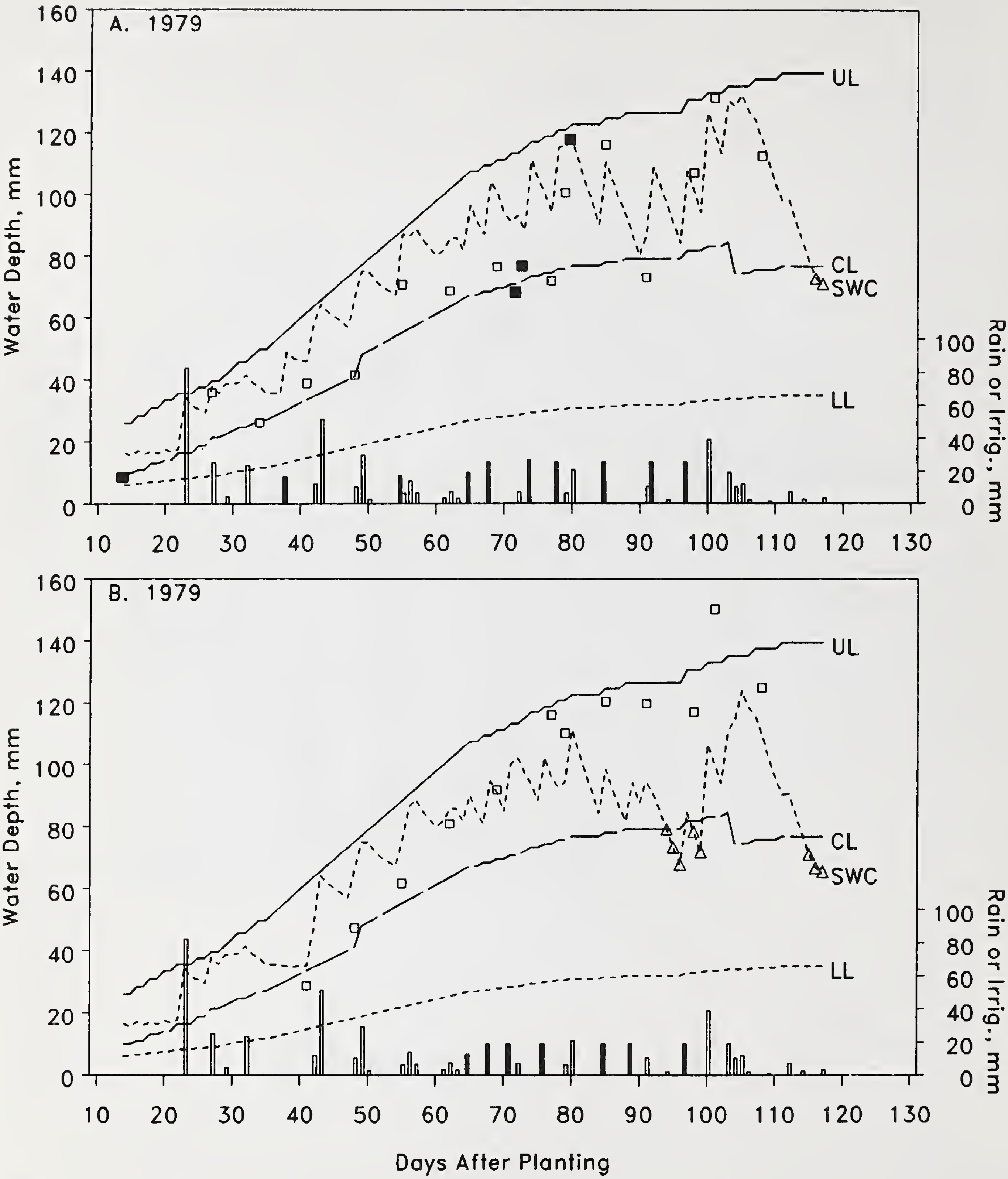

Figure 2.
Daily root-zone water content, irrigation, and rainfall data for (A) irrigated treatment 3 and (B) irrigated treatment 4 at Gainesville in 1979. See figure 1 legend for explanation of symbols.

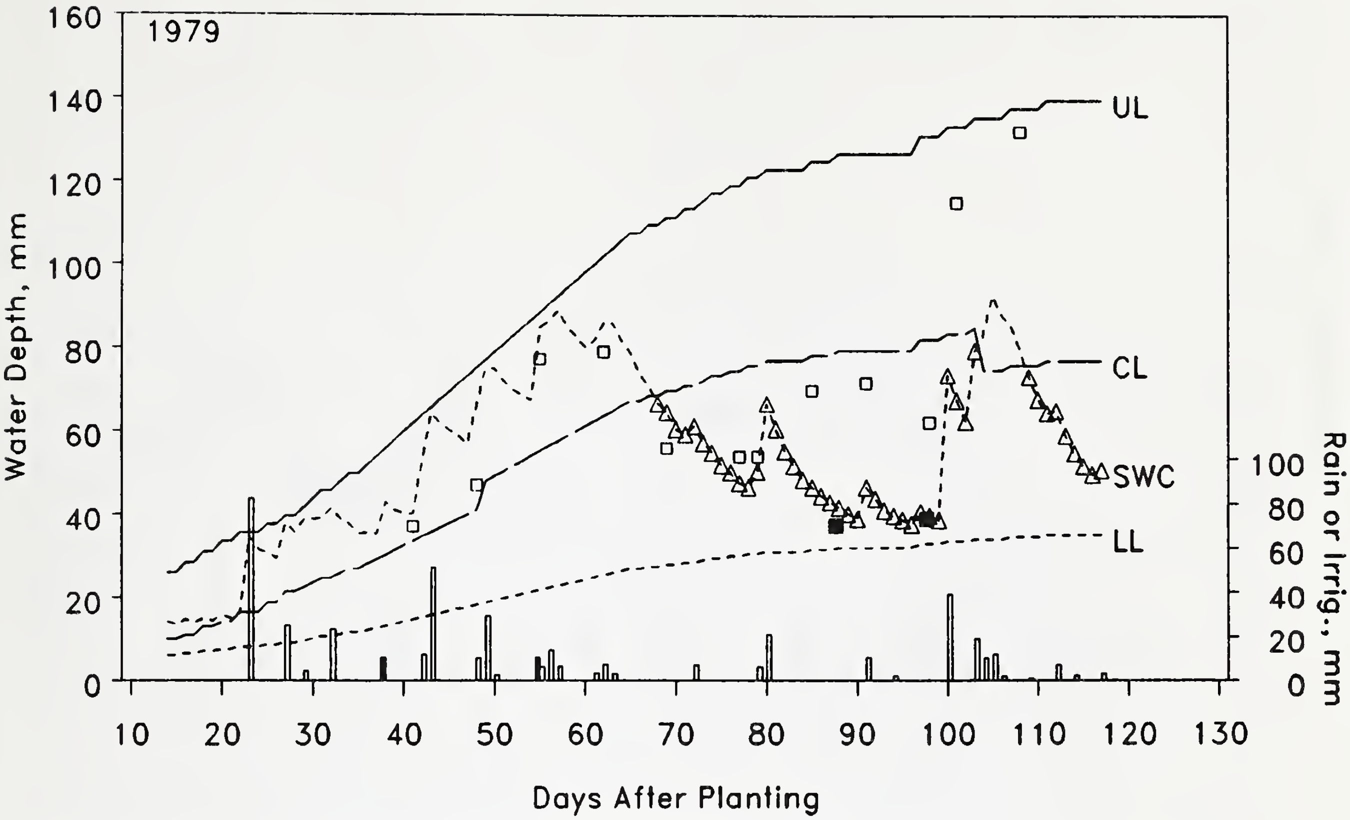

Figure 3.
Daily root-zone water content, irrigation, and rainfall data for irrigated treatment 5 at Gainesville in 1979. See figure 1 legend for explanation of symbols.

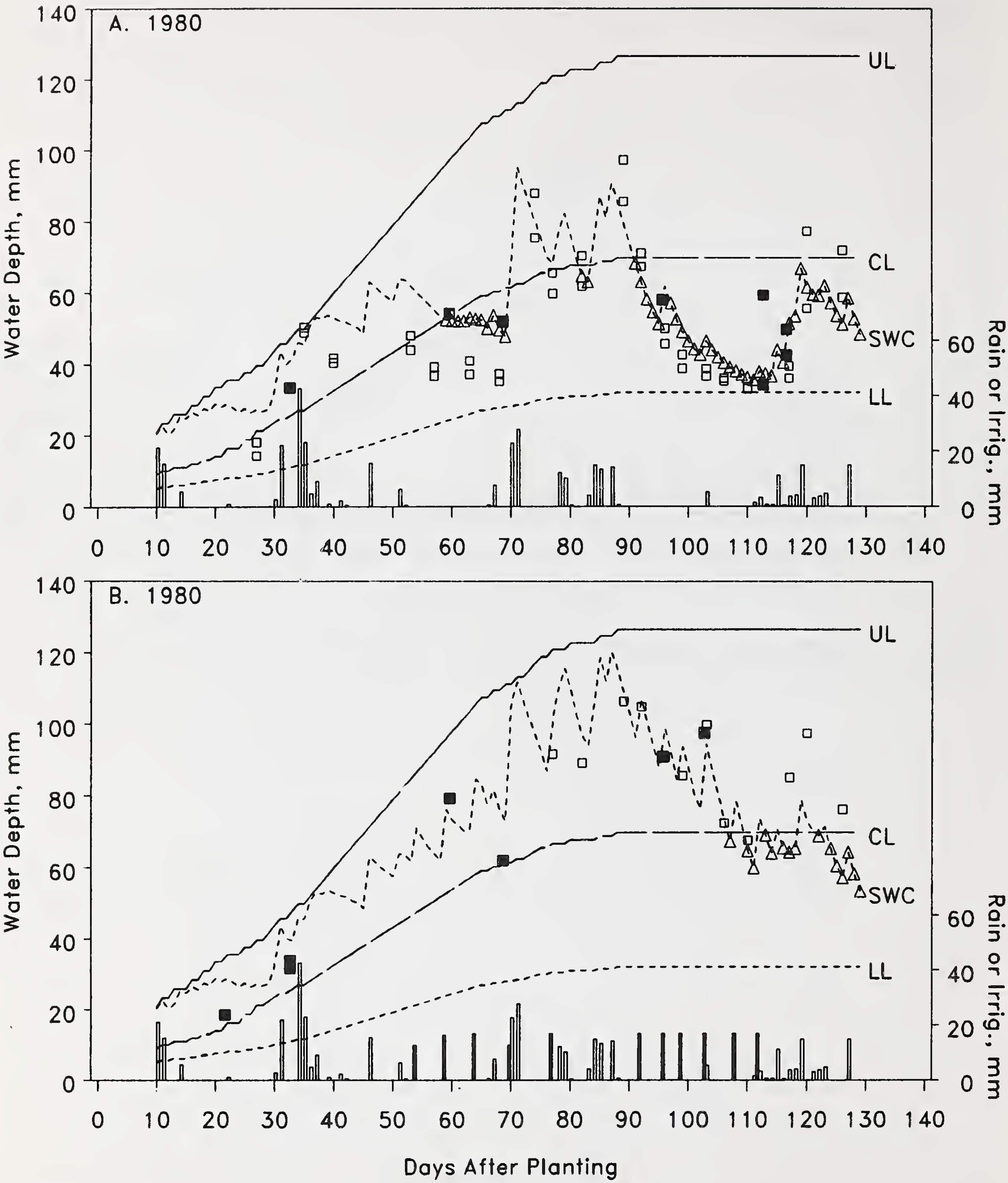

Figure 4.
Daily root-zone water content, irrigation, and rainfall data for (A) rainfed treatment 1 and (B) irrigated treatment 2 at Gainesville in 1980. See figure 1 legend for explanation of symbols.

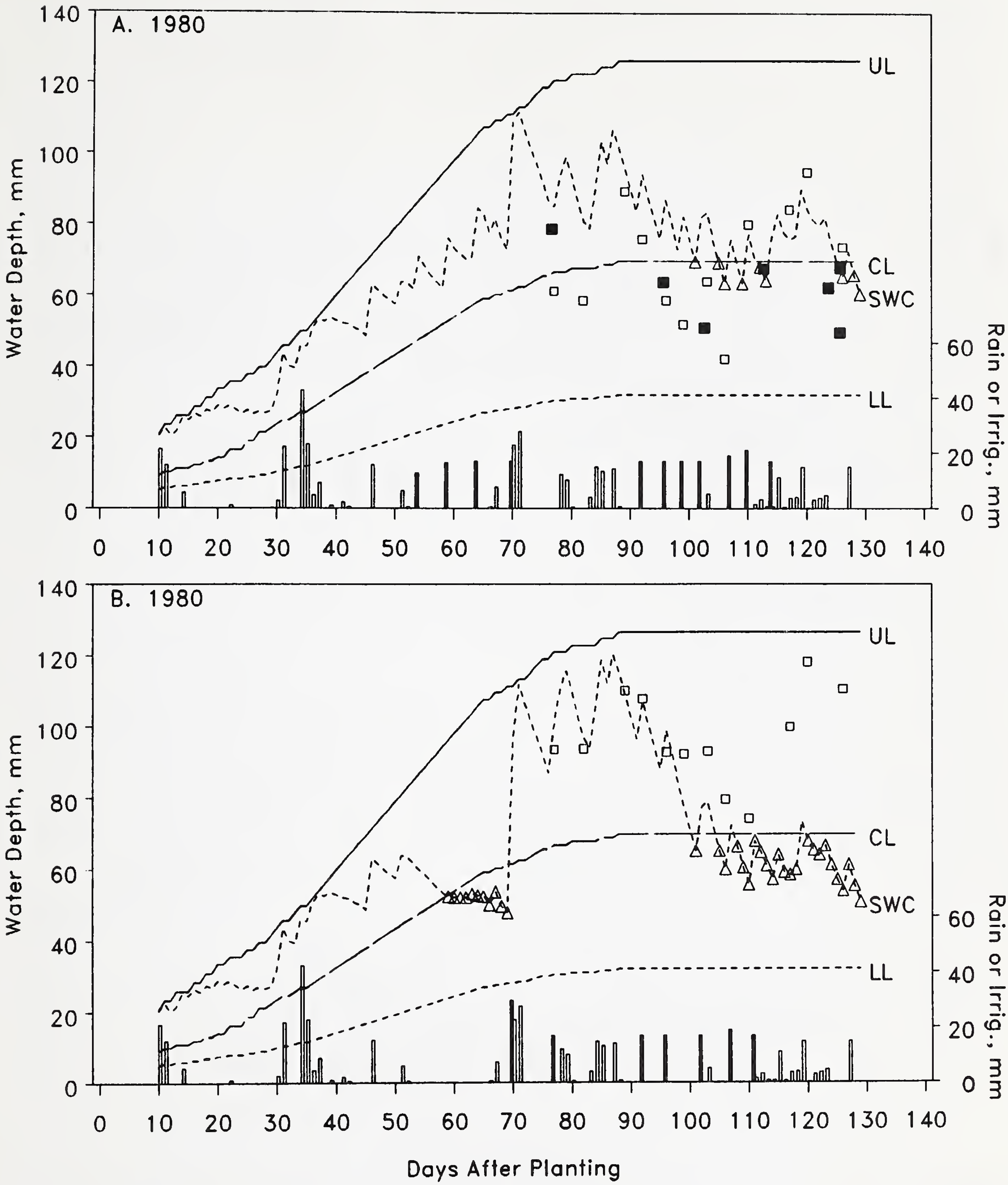

Figure 5.
Daily root-zone water content, irrigation, and rainfall data for (A) irrigated treatment 3 and (B) irrigated treatment 4 at Gainesville in 1980. See figure 1 legend for explanation of symbols.

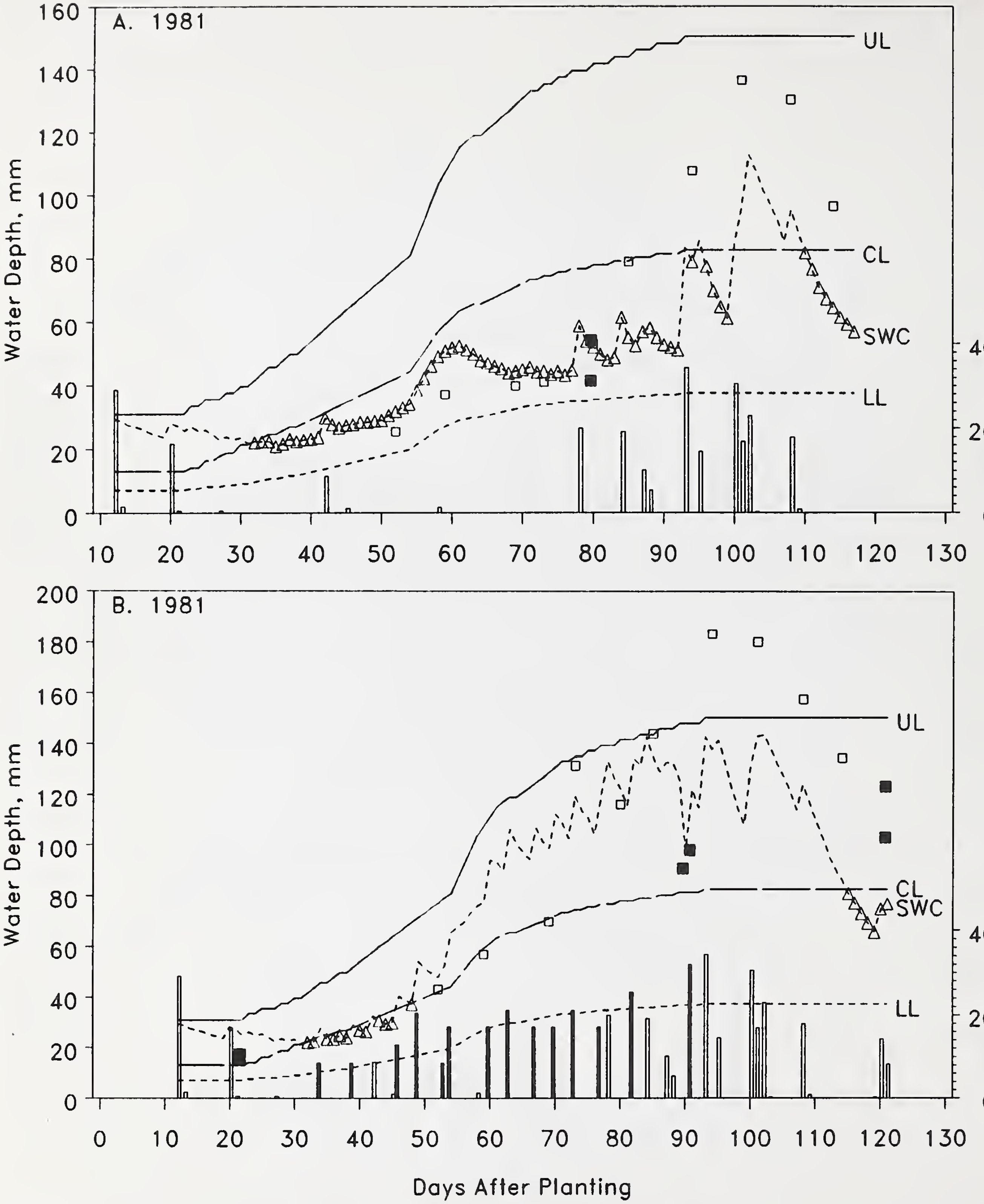

Figure 6.
Daily root-zone water content, irrigation, and rainfall data for (A) rainfed treatment 1 and (B) irrigated treatment 2 at Gainesville in 1981. See figure 1 legend for explanation of symbols.

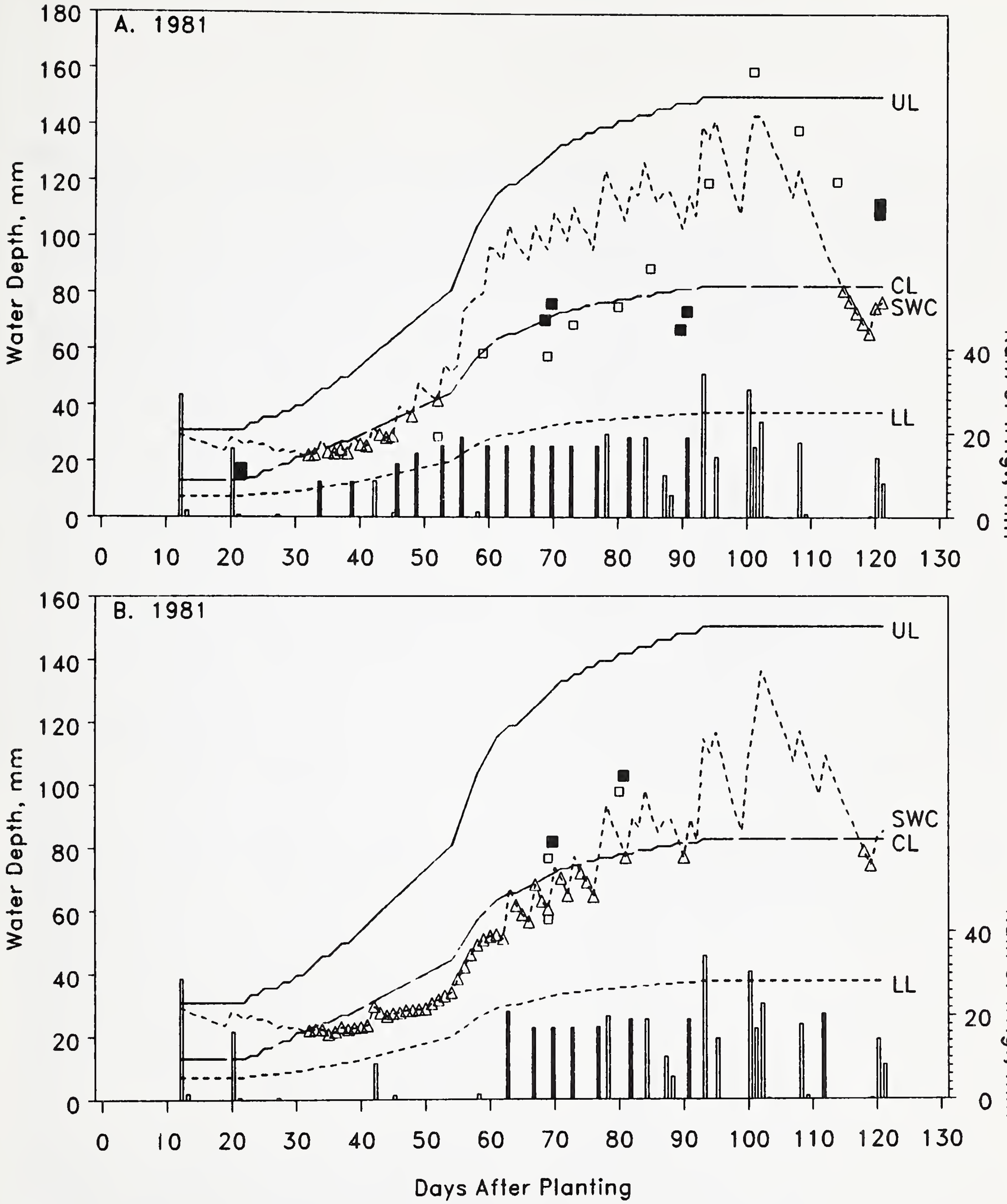

Figure 7.
Daily root-zone water content, irrigation, and rainfall data for (A) irrigated treatment 3 and (B) irrigated treatment 6 at Gainesville in 1981. See figure 1 legend for explanation of symbols.

positive signal for irrigation was accepted when one or more of duplicate SWP's were equal to or less than -20 kPa at the 0.15-m depth. Sixty-one of 80 irrigation events (tensiometers malfunctioned at 6 events) were signaled by the TENS method and 20 by the CBWB method. Forty-six of the TENS signals were at pressures less than -35 kPa. A simultaneous call for irrigation by both methods occurred 12 times; and on 19 occasions, irrigation was scheduled when neither method indicated a need. At other times than those indicated in tables 9, 10, and 11, irrigation need was signaled by CBWB during 29 drought periods. Early-season irrigations were scheduled in eight of those cases (1981) prior to tensiometer installation. Late-season irrigation was signaled by the CBWB method in all irrigated treatments (figs. 1B, 2A and 2B, 3, 4B, 5A and 5B, 6B, 7A and 7B). In 2 of the 10 cases (fig. 7A and 7B), no tensiometer readings were available; but in the other 8, only 4 (all in 1979) gave a positive signal for TENS. Usually TENS was 3 or 4 days earlier than CBWB.

Clearly the TENS method as used in these studies signaled irrigation needs more quickly than the CBWB method, even though in most cases the SWP's at irrigation were much less than the target -20 kPa.

The lack of complete agreement between the TENS and CBWB methods should be expected because of the basic differences in timing criteria selected for each method and the different relationships between these criteria and the strategy of partial refilling of the depleted profile at each irrigation. Efficient water use is the primary consideration, and requires more extensive research with respect to irrigation management strategies.

Soil water pressures throughout the root zone provide information on movement and retention of infiltrated water. This point can be illustrated with the 1980 data shown in table 10. Note that especially at the 0.6-, 0.9-, and 1.2-m depths for treatments 2 and 3, SWP decreased steadily with time after periodic increases. Such increases indicate the arrival of wetting fronts and are clearly seen in treatment 2 for depths of 0.45 m and greater between 69 and 76 DAP. Increases of SWP are also evident at the 0.45- and 0.6-m depths between 99 and 103 DAP--a response to three preceding irrigations. No such increases between 99 and 102 DAP occurred in treatment 3, because the upper profile was drier (lower SWP) than in treatment 2. An entirely different condition was found in treatment 3. Water pressure decreased as in treatment 2 (1.2-m depth) from 92 DAP, but the profile above remained wet, indicating that a wetting front higher in the profile did not move to the 1.2-m depth until 117 DAP (latter data not shown). Furthermore, recorded data not in table 10 indicate that drying continued until 123 and 131 DAP in treatments 2 and 3, respectively, at both 0.9- and 1.2-m depths.

Water extraction patterns were different for subsoiled treatments in 1981 (treatments 5 and 6, table 11). The lower SWP in subsoiled treatments indicate a larger root activity at depths of 0.30 and 0.45 m. However, before reaching a final conclusion, this should be verified by sampling of the root system, since a persistent high soil WC could mask root activity as reflected in measured SWP.

Soil Water Content

In the current study, soil water status was monitored by tensiometer, neutron probe, and gravimetric methods. Results of the last two methods are plotted in all of the CBWB model output graphs (figs. 1-7). In 1979 (figs. 1-3), gravimetric estimates agreed well with the CBWB-predicted soil WC (SWC) except on day 73 of treatment 3, when the gravimetric value was considerably lower. Neu-

Table 9.
Soil water pressure distribution with time and depth prior to irrigation for corn in 1979, Gainesville

Date(DAP)*	Soil water pressure at six depths**					
	0.15	0.30	0.45	0.60	0.75	0.90
	kPa					
Treatment 2***						
5/16(65)	24.7	9.4	8.3	8.6	30.3	--
	45.8	13.2	8.7	8.0	7.7	7.4
19(68)	40.7	10.2	10.9	10.0	73.1	--
	57.1	19.8	9.5	8.5	8.2	8.3
23(72)	11.8	8.6	8.7	12.5	--	--
	56.6	25.2	10.7	9.2	8.8	8.7
27(76)	17.0	7.6	6.5	7.6	--	--
	51.5	17.7	9.7	9.6	9.5	9.4
6/06(86)	16.9	8.4	7.2	7.8	--	--
	60.1	19.8	10.4	9.1	10.7	9.4
10(90)	15.5	8.8	7.5	8.0	--	--
	17.0	21.9	12.0	10.1	11.2	11.6
17(97)	27.5	8.8	7.9	8.0	--	--
	35.4	17.0	12.8	12.6	13.1	15.2
Treatment 3						
5/16(65)	75.3	10.0	8.3	8.1	7.5	16.6
19(68)	70.3	9.0	9.1	10.2	8.3	27.5
26(75)	80.9	8.6	8.6	8.5	8.5	44.1
30(79)	79.5	9.4	6.3	5.9	7.5	47.5
6/06(86)	76.5	11.0	8.1	7.7	7.1	7.8
12(92)	74.7	17.8	9.2	8.3	8.1	49.8
17(97)	44.5	11.4	7.9	6.7	6.8	35.6
Treatment 4						
5/16(65)	24.7	9.0	--	7.0	7.2	7.4
19(68)	62.1	11.0	--	8.2	7.9	8.1
23(72)	12.5	8.6	7.5	8.0	8.5	9.4
27(76)	52.1	9.0	6.7	6.7	6.6	10.6
6/06(86)	31.7	9.7	8.3	7.8	7.5	8.8
10(90)	10.5	9.5	8.2	7.8	7.5	9.7
17(97)	12.7	10.8	8.1	7.8	8.2	31.2

* DAP = days after planting. Dates are 1 day earlier than irrigation except 5/23, 6/6, and 6/10, which were actual days of irrigation.
** Negative sign omitted; depths are in meters.
***Two pressure values on a given date and depth are from duplicate treatments.

Table 10.
Soil water pressure distribution with time and depth prior to irrigation for corn in 1980, Gainesville

Date(DAP)*	Soil water pressure at six depths**					
	0.15	0.30	0.45	0.60	0.90	1.20
	kPa					
Treatment 2***						
4/21(53)	18.9	10.3	8.3	8.9	9.2	8.2
26(58)	53.5	14.4	9.7	10.0	9.2	8.7
5/02(64)	60.0	14.2	11.5	10.2	9.6	9.0
07(69)	34.9	11.5	12.3	11.3	10.5	9.6
14(76)	68.9	10.3	9.0	8.6	6.6	6.1
30(92)	34.5	10.2	8.6	8.6	8.3	8.3
6/03(96)	32.9	12.1	10.1	9.4	9.3	8.8
06(99)	29.8	11.2	10.5	10.6	10.1	9.5
10(103)	14.6	10.4	9.2	10.0	11.2	10.1
15(108)	39.0	11.8	9.8	10.2	13.0	11.1
19(112)	19.7	13.1	11.3	11.0	14.2	12.3
Treatment 3						
4/21(53)	31.4	—	10.2	9.2	9.0	8.5
26(58)	69.1	--	11.2	10.7	10.0	9.6
5/02(64)	71.5	--	11.7	10.3	9.4	9.8
07(69)	74.7	70.0	13.1	11.4	9.2	9.8
30(92)	62.0	23.4	10.5	9.0	12.4	9.9
6/03(96)	75.3	--	21.3	--	14.3	10.6
06(99)	70.9	73.0	36.5	13.0	18.1	11.8
09(102)	66.9	75.0	43.7	16.4	24.4	13.4
14(107)	59.7	72.4	48.8	21.2	35.8	16.8
17(110)	19.5	70.7	48.5	26.9	41.3	17.0
21(114)	10.7	30.8	17.7	32.0	47.4	19.5
Treatment 4						
5/07(69)	71.9	30.0	11.6	11.8	9.4	8.2
14(76)	27.8	10.3	8.5	7.1	6.1	10.7
30(92)	14.7	8.8	6.7	6.8	6.0	7.6
6/03(96)	14.0	9.0	7.1	7.7	7.6	8.7
09(102)	13.1	9.2	8.6	8.6	9.2	11.8
14(107)	12.7	8.4	7.9	6.9	8.5	11.0
18(111)	13.1	8.7	7.9	6.9	6.8	12.7

* DAP = days after planting. Dates represent actual date of irrigation except 5/7, which is 1 day ahead of an irrigation date.
** Negative sign omitted; depths are in meters.
***Data for DAP 64 and 92 are from duplicate treatments.

Table 11.
Soil water pressure distribution with time and depth prior to irrigation for corn in 1981, Gainesville

Date(DAP*	Soil water pressure at six depths**					
	0.15	0.30	0.45	0.60	0.90	1.20
	kPa					
Treatment 2						
5/01(53)	57.5	8.6	6.9	9.2	9.0	8.5
08(60)	76.6	12.0	12.6	9.1	9.0	8.7
11(63)	51.7	10.9	22.3	10.9	9.4	9.0
15(67)	66.2	9.5	21.5	9.6	10.9	9.5
18(70)	67.8	11.8	47.8	18.6	12.8	10.2
20(72)	25.1	8.1	53.9	22.0	15.7	10.9
25(77)	63.5	10.6	16.5	10.2	25.0	26.0
30(82)	28.5	9.0	8.4	10.2	8.0	19.0
6/08(91)	15.9	12.1	12.7	11.2	8.1	7.6
Treatment 3						
5/01(53)	21.0	23.8	--	10.3	7.8	7.0
04(56)	37.1	35.6	--	11.6	8.0	7.8
08(60)	12.5	11.0	--	--	9.8	9.0
11(63)	26.0	10.0	--	7.0	9.1	8.5
15(67)	67.2	19.1	8.0	--	12.0	9.0
18(70)	71.5	42.4	13.7	10.2	13.6	9.2
20(72)	33.5	11.2	--	11.6	16.2	9.9
25(77)	71.5	54.1	--	11.3	25.6	16.4
30(82)	25.3	15.4	--	9.2	7.0	14.6
6/08(91)	15.3	14.9	--	9.5	11.2	24.0
Treatment 5 - No subsoil						
5/01(53)	55.9	15.2	7.3	8.1	10.3	--
05(57)	--	9.4	10.2	9.4	8.6	8.2
08(60)	11.1	10.6	12.7	10.0	9.0	8.7
11(63)	15.9	11.9	8.5	9.5	8.5	8.4
15(67)	54.3	15.2	7.3	9.6	9.1	8.5
18(70)	54.2	36.2	8.5	8.4	9.0	8.6
22(74)	--	43.7	12.9	9.4	10.0	9.1
26(78)	--	--	--	10.0	11.4	10.1
30(82)	58.2	27.5	7.9	6.4	11.2	9.8
6/08(91)	62.0	33.4	9.9	6.9	10.2	10.1

See footnotes at end of table.

Table 11--Continued
Soil water pressure distribution with time and depth prior to selected irrigation events for corn in 1981, Gainesville

Date(DAP)*	Soil water pressure at six depths**					
	0.15	0.30	0.45	0.60	0.90	1.20
	---------------------kPa---------------------					
Treatment 5 - Subsoil						
5/01(53)	14.1	6.8	9.3	8.2	7.5	7.5
05(57)	--	20.3	11.6	9.2	8.2	8.0
08(60)	8.7	28.1	13.0	9.2	8.2	8.8
11(63)	12.3	28.3	18.0	7.3	8.5	8.3
15(67)	37.5	48.8	33.0	7.7	8.2	8.6
18(70)	27.1	57.6	41.4	8.7	8.3	8.8
22(74)	--	67.4	55.3	10.7	8.8	9.1
26(78)	--	54.8	61.9	--	10.0	10.0
30(82)	61.9	57.1	35.7	7.0	7.2	9.8
6/08(91)	56.7	60.1	48.8	9.4	7.2	10.9
Treatment 6 - No Subsoil						
5/11(63)	36.3	17.2	11.5	9.2	8.4	7.8
15(67)	--	9.2	12.8	9.2	8.6	8.1
18(70)	--	6.6	9.0	9.0	8.8	8.4
22(74)	--	--	6.2	5.4	8.8	8.5
25(77)	11.2	7.8	6.3	5.8	9.8	6.0
30(82)	--	--	--	--	--	--
6/08(91)	20.3	9.4	8.6	7.7	5.8	4.6
Treatment 6 - Subsoil						
5/11(63)	43.0	39.9	64.3	8.8	7.1	6.3
15(67)	--	52.6	69.2	9.7	7.5	7.0
18(70)	--	--	68.1	10.6	8.1	7.4
22(74)	--	--	54.3	8.2	8.0	7.3
25(77)	21.5	47.1	15.1	--	10.0	8.6
30(82)	33.1	52.5	12.3	5.9	4.2	7.8
6/08(91)	26.3	46.7	13.5	7.1	5.1	4.5

* DAP = days after planting. Dates are 1 day ahead of the irrigation date in most cases.
** Negative sign omitted; depths are in meters.

tron probe estimates, on the other hand, tended to deviate widely from the SWC. A tracking change occurred in treatments 2, 4, and 5 on day 86, when there was an overresponse to rainfall (increase in measured WC greater than rainfall amount). Four of six neutron probe sites (including treatments 1 and 3) showed this response, with the effect continuing to season's end. Also, there was an overresponse at two sites (treatments 1 and 5) to the large rainfall on day 101. The consistently low neutron probe values in early season could be associated with the shallow root depths, where it is difficult to measure WC with the neutron probe.

In 1980 (figs. 4-5), early-season neutron probe estimates of soil WC were available only for treatment 1. Estimates were again low except for the very wet situation on day 35, when there was good agreement with SWC values (fig. 4A). There was only one obvious overresponse of a neutron probe site to irrigation and rainfall (day 116, treatment 4, fig. 5B). Otherwise, neutron probe data tracked SWC reasonably well. Gravimetric data were in agreement with SWC values, with the exception of low values on days 96 and 103 in treatment 3 (fig. 5A).

The very dry season of 1981 produced interesting differences in measured and simulated WC. The tensiometer, CBWB, and neutron probe methods of estimating soil WC agreed well in treatment 1 until day 86, when there was an over-response of the neutron probe measurements to rainfall (fig. 6A). The high neutron probe results persisted for the remainder of the season. Irrigated treatments 2 and 3 (figs. 6B and 7A) contrasted sharply with the rainfed treatment. Neutron and gravimetric results were in general agreement, but they differed from SWC on most measurement dates. Gravimetric WC values were lower than SWC values on day 91 but were higher at season's end. Neutron-measured WC values varied widely from below SWC values (50 to 95 days) to consistently higher than SWC on days 102, 109, and 116. The high measured soil WC on 103 DAP (fig. 7A) and 95, 102, and 109 DAP (fig. 6B) is evidence that drainage losses of the magnitude predicted by the CBWB did not occur (see tables 12 and 13 and later discussion).

Simulated and measured soil WC in figures 1-7 do not show distribution with soil depth. Measured WC distribution data in tables 14 and 15 were selected to show the water retaining characteristics of the soil profile, patterns of plant water extraction, and a comparison of water measurement methods. There was good agreement between neutron probe and gravimetric WC (table 14), with all three treatment-replicate sampling sites being relatively uniform for an intermediate-term drainage condition. Rainfall amounts of 53, 22, 3, and 4 mm had occurred 30, 21, 16, and 4 days earlier, respectively. An increase in soil WC and variability between sites at depths greater than 1.65 m was associated with a texture change from fine sand to sandy clay.

Data in table 15 are typical of results found throughout the 3-year study for very dry and mixed-wet-dry soil profiles. Gravimetric and neutron probe measurements under dry conditions (rainfed, 6/19) were in close agreement in terms of distribution with depth throughout the root-zone (1.45 m). Equivalent water depths were 33, 40, and 38 mm for the gravimetric, neutron probe, and simulated estimates. The 6/22 data, from four sites sampled 24 hours after a rainfall of 39 mm, disclosed an important finding relative to methods of measurement and spatial variability. In the wet part of the soil profile, there was generally good agreement between neutron probe and gravimetric soil WC, with neutron probe values being slightly higher than gravimetric values. Moreover, the three

Table 12.
Simulated drainage from the root zone of corn under various water management treatments, 1979, Gainesville

DAP*	Drainage 1**	2	3	4	5
	----------------	----------------	mm	----------------	----------------
24	78	78	78	78	78
28	17	17	17	17	17
33	17	17	17	17	17
44	35	37	45	35	40
50	20	20	20	20	20
51	1	1	1	1	1
56	--	--	4	--	--
57	--	10	13	--	10
58	3	3	3	3	3
69	--	--	3	--	--
79	--	--	1	--	--
80	--	--	1	--	--
81	--	--	15	--	--
101	--	--	2	--	--
105	--	--	5	--	--
106	--	--	6	--	--
Total	168	181	228	168	183

* Days after planting on 3/13.
** Treatment numbers; see description, table 6.

neutron-probe sites were uniformly wet throughout the top 0.60 m of soil. This means that the high variability observed in root zone WC (figs. 1-7) was due largely to variations in the depth of wetting. In addition, spatial variability is reduced when water input is sufficient to refill depleted subsoil water throughout an experimental site (table 14).

Root zone (1.48 m) equivalent water depths as calculated from the profile volume fractions of water were 145, 118, and 98 mm (6/22 irrigated-sample sites, left to right, table 15). The last value (gravimetric) was actually equal to the simulated value. Also, note the previous history relationship for the two neutron-probe sites on 6/19 and 6/22. Both sites gained 33 mm of water from the 39 mm of rainfall. Contrast this with the apparent gain of 65 mm in the rainfed site. Clearly, there was enhanced input of water in the vicinity of the neutron access tube at this site. Comparisons of the neutron probe and gravimetric data support the conclusion that the instrument was not malfunctioning during these measurements.

Additional useful observations can be made from the data in table 15. Contrast these soil WC with the input values used for the CBWB (table 2). Measured values which were greater than projected for the UL clearly support the conclusion that "excess water" can be stored in the soil

Table 13.
Simulated drainage from the root zone of corn under various water management treatments, 1980-1981, Gainesville

DAP*	Drainage			
	1**	2	3***	4
	mm			
1980				
10	23	23	23	23
11	15	15	15	15
14	1	1	1	1
31	10	10	10	10
34	34	34	34	34
35	19	19	19	19
37	8	8	8	8
70	--	--	2	9
71	--	22	25	2
87	--	2	--	--
Total	110	134	136	120
1981				
13	30	30	30	30
21	9	9	9	
94	--	13	--	--
96	--	5	--	--
103	--	16	15	--
Total	39	73	54	39

* Days after planting (2/28 and 3/10 in 1980 and 1981, respectively).
** Treatment numbers; see description, table 6.
***In 1981, the drainage data for treatments 5 and 6 were the same as shown for treatments 3 and 4, respectively.

profile for periods longer than one day. Use of a time-drainage submodel would give better results than a simple upward revision of the UL values in table 2 when one takes into consideration the values for well-drained soil in table 14. Lower-limit values for the CBWB (table 2) may be slightly high, since soil WC values as low as 0.018 volume fraction were measured (gravimetric and neutron probe).

Water content distribution patterns in table 15 (for 6/22) reflect the depths of rooting, 1.65 m at least for the rainfed plot and 1.35 to 1.50 m for the irrigated plot. Root depths projected by the CBWB (table 8) were 1.48 and 1.55 m (maximum) for 6/22 and 7/1, respectively. In 1980, depletion of water at a depth of 1.8 m was observed, although the maximum root depth was projected to be only 1.4 m.

Table 14.
Soil profile water content under corn at 3 sites, 27 March 1979, Gainesville

	Water content, volume fraction					
	Gravimetric			Neutron Probe		
Depth	I-1*	I-2	II-3	I-1	I-2	II-3
(m)	m^3/m^3					
0.15	0.074	0.075	0.072	0.061	0.085	0.068
0.30	0.077	0.079	0.080	---	---	---
0.45	0.061	0.079	0.069	0.075	0.084	0.074
0.60	0.069	0.074	0.066	0.075	0.087	0.073
0.75	0.066	0.072	0.064	0.070	0.078	0.069
0.90	0.068	0.070	0.064	0.064	0.073	0.065
1.05	0.066	0.069	0.087	0.062	0.075	0.062
1.20	0.062	0.074	0.063	0.062	0.072	0.068
1.35	---	---	---	0.062	0.072	0.064
1.50	0.058	0.080	0.058	0.067	0.074	0.068
1.65	---	---	---	0.069	0.085	0.068
1.80	0.069	0.095	0.068	0.077	0.097	0.068
1.95	---	---	---	0.087	0.103	0.077
2.10	0.118	0.099	0.189	0.109	0.110	---

* Replication and treatment numbers.

Water depletion levels for the subsoil (0.9 to 1.5 m) were the same under both rainfed and irrigated conditions (table 15, 6/22). Such results, typical of those which were obtained during droughts in each year of the study, were a consequence of the irrigation strategy used -- light, frequent irrigation with incomplete filling of the depleted profile. This strategy resulted in failure of irrigation to increase soil WC above the CL in many cases. The strategy could be called deficit irrigation as generally defined, where "...irrigated rates are less than estimated evapotranspiration rates" (Miller and Aarstad 1976). Nevertheless, deficit irrigation can be programmed to satisfy the evaporative demand of the atmosphere with water supplied from (1) frequent irrigations of the upper root zone, (2) further depletion of the lower root zone, and (3) previously untapped sources as roots extend to greater depths.

The CBWB estimates the soil water stored in the plant root zone. Verification of this estimate would require extensive measurement of soil WC over time and over the cropped land area, characteristics of which have been included in the model. Variable results from limited sampling of multiple sites in this study show that sampling was not adequate for CBWB verification. There were numerous cases where sequential and nondestructive measurements by neutron probe failed to reflect water input events quantitatively. A 39-mm rainfall on 101 DAP in 1979 was measured as an increase in soil WC of 24, 25, 32, 34, 50, and 64 mm at five neutron probe measurement sites. Causi-

Table 15.
Soil water content distribution with depth for rainfed and irrigated water management treatments before and after a drought-ending rainfall, Gainesville, 1979

	Water content, volume fraction*							
	Rainfed			Irrigated**				
Depth	6/19		6/22***	6/19		6/22		
(m)	m^3/m^3							
0.15	0.029	0.025	0.097	0.075	0.057	0.102	0.078	0.113
0.30	0.036	---	---	---	---	---	---	0.108
0.45	0.029	0.020	0.119	0.099	0.092	0.114	0.115	0.109
0.60	0.025	0.029	0.125	0.102	0.081	0.117	0.126	0.104
0.75	0.025	0.024	0.089	0.086	0.054	0.118	0.115	0.098
0.90	0.024	0.020	0.035	0.071	0.044	0.116	0.081	0.019
1.05	0.024	0.018	0.018	0.061	0.040	0.101	0.045	0.018
1.20	0.021	0.018	0.019	0.056	0.037	0.073	0.037	0.021
1.35	---	0.021	0.020	0.058	0.041	0.056	0.038	0.034
1.50	0.031	0.029	0.023	0.062	0.041	0.059	0.041	0.037
1.65	---	0.036	0.034	0.074	0.042	0.068	0.040	0.050
1.80	0.082	0.053	0.048	0.091	0.050	0.085	0.048	0.051
1.95	---	0.064	0.062	0.098	---	0.091	---	0.081
2.10	0.108	0.088	0.079	---	---	---	---	0.187

* Neutron probe measurements, except for gravimetric values in the first and last columns of data.
** Treatment 2.
***All measurements on 6/22 were made about 24 hours after a rainfall of 39 mm.

tive factors include uneven infiltration of rainfall due to surface runoff, short-term ponding in small depressions, and channeling of water through the plant canopy. Aside from the problem of model verification, there are possibilities for calibrating models for specific sites. Riestra-Diaz (1984) successfully calibrated a model similar to the one used here by adjustment of the time-drainage submodel.

Water Balance

The CBWB allocates input water to soil storage, evaporation, and drainage on a daily basis, assuming no surface runoff. The evaporation submodel is a dynamic and biologically- and climatologically-sensitive part of the CBWB. Drainage is a daily event resulting when water input minus estimated evaporation exceeds the difference between the fixed UL and the SWC on that day. Since this is not a very precise model of the actual drainage process, there is room for improvement in the CBWB. Unfortunately, there are no suitable means for measuring drainage from the root zone, and we are left with measurement of soil WC as the only means of verifying water balance models.

Seasonal measured water input, simulated evaporation (actual evapotranspiration,

AET), and simulated drainage data are given in tables 5 and 6. Tables 12 and 13 contain daily simulated drainage losses. Simulated seasonal AET under rainfed conditions was highest and equal in 1979 and 1980 even though rainfall was highest in 1979, clearly showing the effect of rainfall distribution. Within each season, AET increased with seasonal irrigation amounts.

Irrigation increased simulated drainage losses in all but two treatments (initiation of irrigation at tasseling in 1979 and 1981). Some increase in stored soil water occurred since the efficiency was still less than 1 in these cases. Heavy, early-season rainfalls in 1979 resulted in large amounts of predicted drainage from the shallow crop root zone (table 12). Calculations showed that 63, 81, and 70% of the first two irrigations were predicted as lost by drainage from the root zone by day 58 in treatments 2, 3, and 5, respectively. Such findings emphasize the difficulty of obtaining efficient use of irrigation in humid regions. Note that the treatment with the largest amount of irrigation per event (treatment 3) continued to show drainage for the remainder of the season. Early-season drainage losses in 1980 were less than in 1979 by about 60 mm (for the rainfed treatments), although midseason drainage losses occurred for all three irrigation treatments. Drainage was much less in 1981 than for the two previous years of study.

The proportions of seasonal irrigations which were predicted to be of use in increasing seasonal AET are shown under the "irrigation efficiency" column in table 6. They were surprisingly high (averaging 0.8) and uniform across treatments and years. Exceptions were for treatments 3 and 5 in 1979, where the efficiencies were only 0.6 and 0.2, respectively. For treatment 3, medium irrigation amounts per event resulted in a large seasonal amount of irrigation. This, in turn, caused a large increase in simulated seasonal drainage loss. On the other hand, treatment 5 received only 21 mm of early-season irrigation, when frequent rainfalls caused periodic drainage losses.

Yield-Water Relationships

Our discussion thus far has dealt with the consequences of various water management treatments in terms of temporal differences in soil WC and SWP and of seasonal water balance. A next logical step is to explore the relationships between such physical responses and yields of corn grain. Grain yields for all water management treatments in the 3-year study are given in table 16. Yields were lowest and most variable in 1979 because of residual effects from previous experiments in the field-plot area. In 1981, high winds on 18 June caused severe lodging of the corn, especially for the

Table 16.
Yield of corn grain under various water management regimes during 1979-1981, Gainesville

Treatment*	Grain yield 1979	1980**	1981***
	------ Mg/ha	------	
1	1.43	3.99	1.42
2	5.12	10.19	6.24
3	5.19	9.55	5.86
4	4.25	6.99	0.83
4 (Subsoiled)	-	-	2.36
5	2.06	-	6.51
5 (Subsoiled)	-	-	7.71
6	-	-	3.42
6 (Subsoiled	-	-	5.61

* Description specific for each year; see table 6.
** Averages for 2 hybrids.
***Averages for 4 hybrids.

irrigated plots. Grain-filling time was shortened, and yields were reduced. In both 1980 and 1981 some reduction in yield resulted from infestations by red spider mites. Subsoiling in 1981 resulted in marked yield increases over the nonsubsoiled treatments, probably as a result of the enhanced water supply created by increasing the volume of soil explored by the corn root system.

No clear effects of light versus medium irrigation events, or of TENS versus CBWB scheduling methods were evident. However, data clearly show that a water deficit of 10 days or more at any growth stage can result in significant yield reductions in comparison with well-irrigated conditions (table 16). Delaying the beginning of irrigation until tasseling produced lower yields than season-long irrigation, by 2-3 Mg/ha in both 1980 and 1981 (treatments 4 and 6, respectively). Since serious irrigation needs did not develop before the beginning of tasseling in 1979 (fig. 1B, 2B), the low yield in treatment 4 was probably due to factors other than delayed irrigation.

Corn grain yield responses to seasonal irrigation and AET are shown in figures 8-10. These data yield two linear crop-water production functions. Correlation coefficients were based on replicate data rather than on the means shown. Regression coefficients are indicative of the yield increase per unit of irrigation or AET (Mg/(ha mm). If all applied water were used to increase AET, the two production functions would be the same (Stewart and Hagan 1973). The smaller slope of the irrigation function reflects the average inefficiency of the several irrigation management treatments in a particular season. An estimate of the average fraction of applied water which was used as AET is given by the ratio of regression coefficients, irrigation:AET. Irrigation-water-use efficiencies as defined by this ratio were 0.73, 0.81, and 0.80 for the 1979, 1980, and 1981 seasons, which were similar to efficiencies calculated for individual treatments (table 6).

Higher variation in the yield data of 1979 than in those of 1980 and 1981 can be noted in the much lower R^2 values of 1979 (figs. 8-10). Although much of the variation from linearity was due to differences among replicates, there was additional variation due to treatment. As indicated earlier, the yield of treatment 4 was lower than expected in comparison with treatment 2. The latter received only 19 mm of additional irrigation. Furthermore, there was no yield increase in treatment 3 over treatment 2 when 59 mm of additional irrigation was received by treatment 3. This is an example of nonlinearity in the irrigation response, which can occur with untimely irrigation scheduling and unexpected rainfall events and amounts (Stewart et al. 1975, Stegman et al. 1980). The production function slopes found in this study are in the range reported by others (Stewart et al. 1977, Hook et al. 1984).

Yield response to irrigation as affected by subsoiling in experiment 2 (1981) is shown in figure 11. Subsoiling apparently enhanced the supply of plant available water, which resulted in higher grain yields. Even though the production function of the subsoiled treatment was shifted to higher yields, the slopes of the two functions were essentially the same. In an earlier study of corn, Robertson et al. (1981) tested three levels of seasonal water input and two row spacings--0.46 and 0.92 m--at a constant plant density (seven plants/m^2). Grain yields were higher for the closer row spacings, and slopes of the two irrigation production functions were similar--0.046 and 0.042 Mg/(ha·mm), respectively, for the two row spacings. Apparently, the narrow-row arrangement of plants increased both the efficiency of light interception and AET.

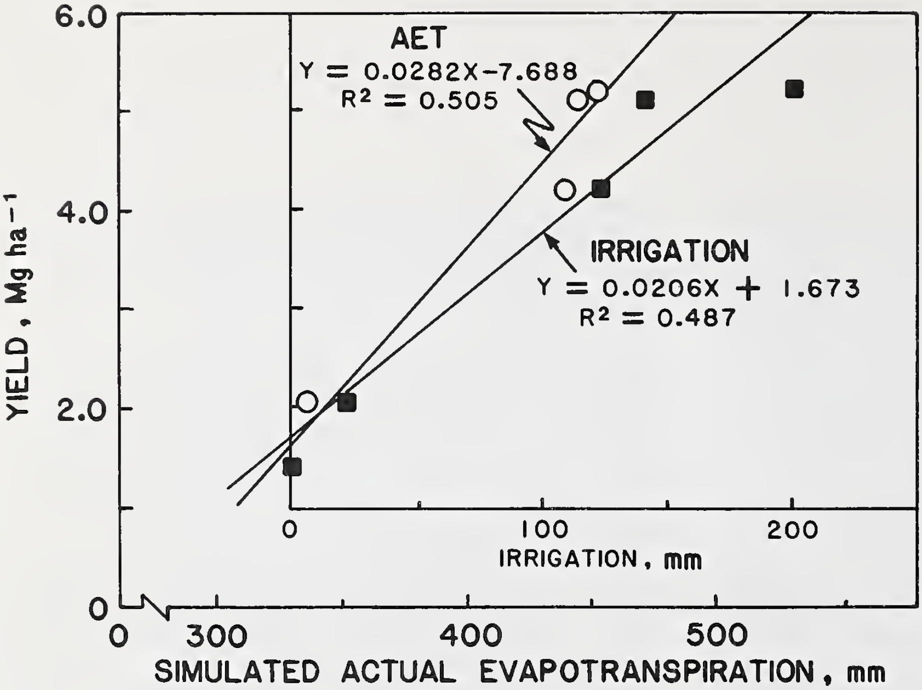

Figure 8.
Corn grain yield in relation to seasonal irrigation and simulated actual evapotranspiration, 1979.

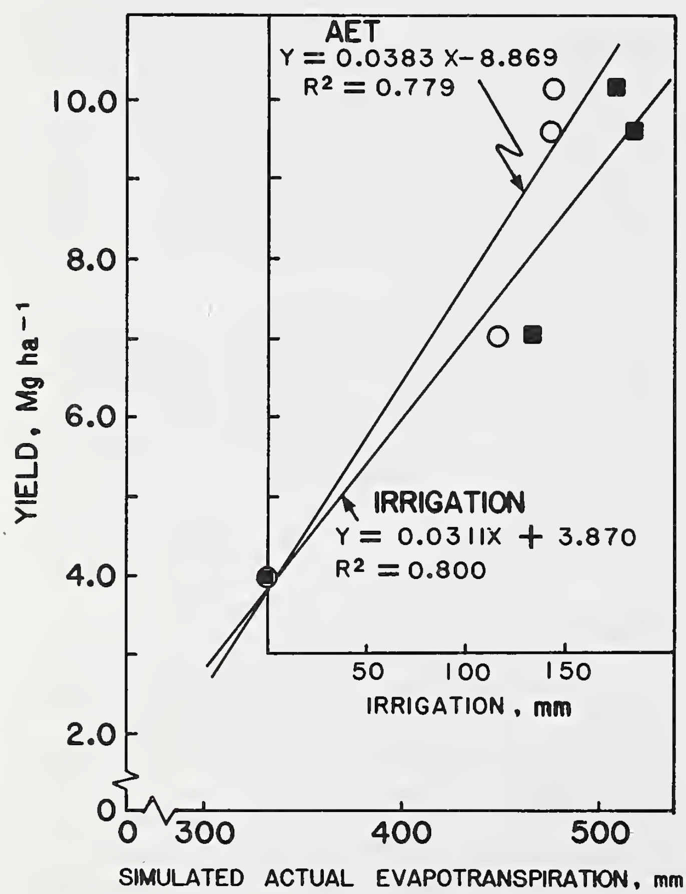

Figure 9.
Corn grain yield in relation to seasonal irrigation and simulated actual evapotranspiration, 1980.

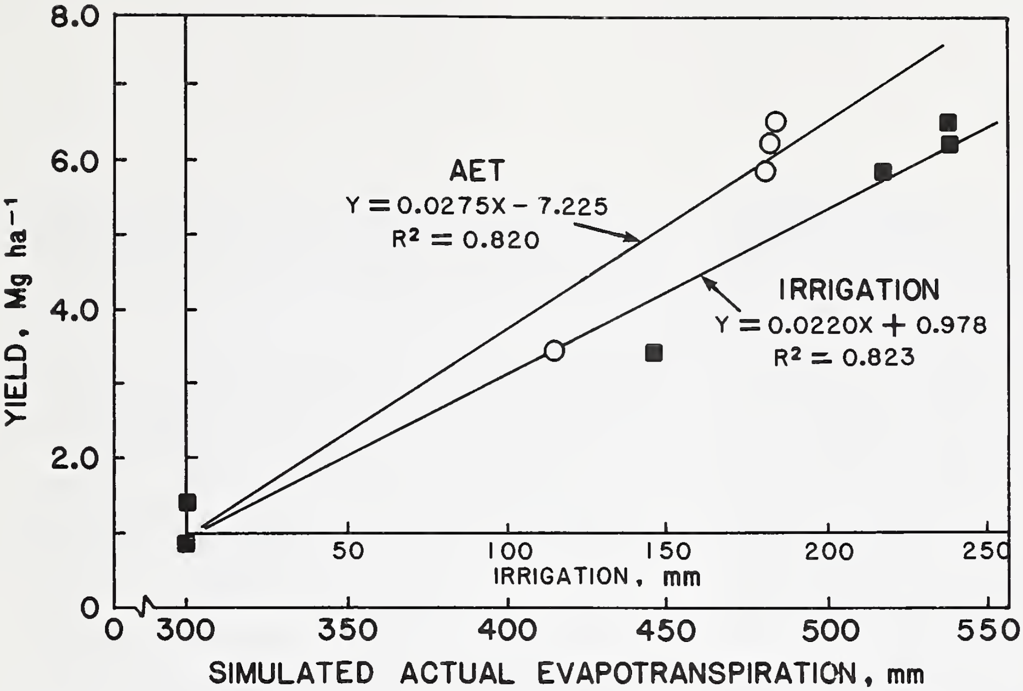

Figure 10.
Corn grain yield in relation to seasonal irrigation and simulated actual evapotranspiration, 1981.

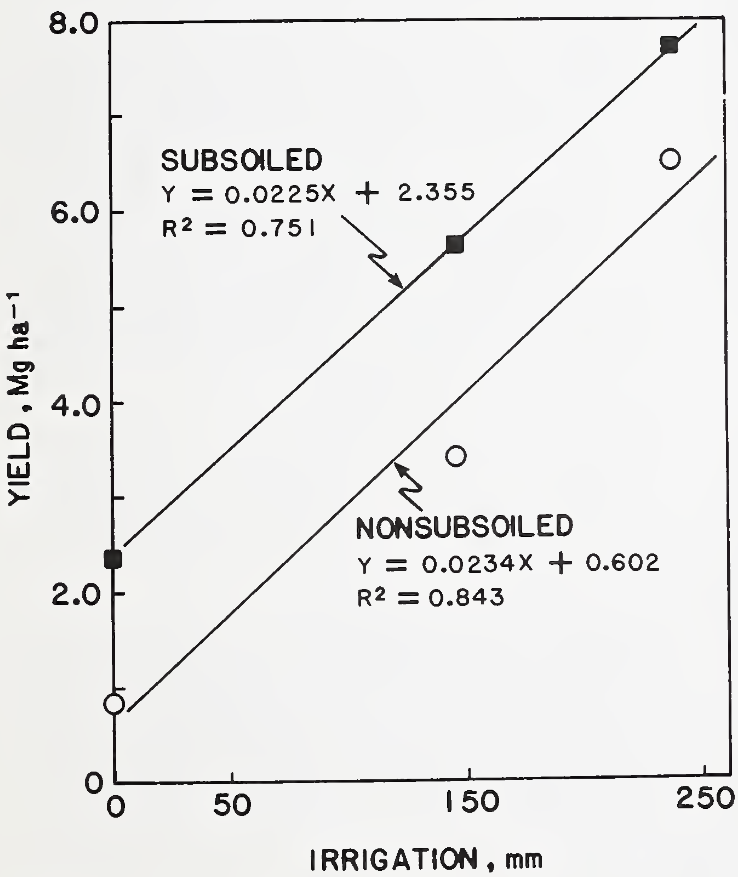

Figure 11.
Corn grain yield in relation to seasonal irrigation as affected by subsoiling, experiment 2, 1981.

A single AET production function may be common to two or more irrigation functions of a factor such as subsoiling or planting pattern. On the other hand, complex interrelationships of harvest index, root-shoot ratio, and transpiration-AET ratio might be expected to result in AET production functions unique to each irrigation function. When a common AET production function is appropriate, graphical representations analogous to figures 8-10 will show two or more irrigation abscissas with different origins on the yield-AET curve.

CONCLUSIONS

A 3-year study of irrigation scheduling on corn in Florida gave results which strongly justify the use of high-frequency irrigation in this area. In the third year, subsoiling to break up the plowpan increased grain yields by an average of 45%. Grain yield response to water management was related largely to seasonal quantities of irrigation and to simulated actual evapotranspiration, rather than to scheduling methods and strategies. In general, findings in terms of irrigation-use efficiency support the strategy of leaving room in the soil profile for subsequent storage of rainfall.

The irrigation scheduling model (CBWB) used in this study proved to be a very useful tool for analyzing water management results. Further efforts in model development, verification, and calibration seem justified. Results from monitoring the soil water status (tensiometer, neutron probe, and gravimetric) revealed large spatial variabilities, especially at times when irrigation was needed. This factor makes model verification both difficult and costly, because of the extensive sampling required to obtain satisfactory estimates of soil WC. For irrigation scheduling at the farm level, it appears that the CBWB could be used successfully and, perhaps, with a competitive advantage over scheduling based on soil water measurements.

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9. SUFFOLK, VIRGINIA

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INTRODUCTION

Several methods of irrigation scheduling have been described earlier in this publication. All previous discussions regarding those methods apply to the Virginia Coastal Plains, since it is part of the humid Southeast. Although corn does not rank high as a cash crop in this area of Virginia, it is very important as a rotational crop with peanut and soybean, and it responds well to the application of irrigation water.

This chapter describes the results of scheduling irrigation on corn using a water balance simulation model. Tillage and agronomic factors were included in the 4-year study, and the results are described in a separate paper (Wright et al. 1984).

The application of the water balance simulation model was not compared with that of other scheduling methods as described in previous chapters of this report. However, the success of this approach was verified by measuring soil water content (WC) in the field and by measuring corn grain yield each growing season.

MATERIALS AND METHODS

This irrigation scheduling study for corn was conducted on a private farm in the Coastal Plains region of Virginia, near Carrsville in Isle of Wight County. Corn was rotated with peanuts so that corn planted in 1980 and 1982 was on the same site, and corn planted in 1981 and 1983 was on the same site. The soil for both locations was classified as a Norfolk loamy fine sand (Typic Paleudult). The soil profile description and soil water retention data for the two sites are given in tables 1 and 2.

The experimental design was a split-split plot with four replications of each treatment within nonirrigated and irrigated blocks. Treatments within each block were the same. They consisted of low and high plant populations (55,700 and 70,500 plants/ha, respectively) and nonripping and ripping under the plant row (Wright et al. 1984). Underrow ripping was performed to a depth of 0.3 to 0.4 m to penetrate the E soil horizon.

A corn hybrid, Pioneer 3369A, was planted during the first 3 weeks of April each year. Test plots were disked twice and planted with conventional equipment. Plant nutrients such as phosphorus, potassium, zinc, and other minor elements were applied by broadcasting prior to land preparation at a rate based on soil analyses.

For the nonirrigated block, nitrogen solution with sulfur (28-0-0-2) was supplied in two applications, one at planting and the other when corn plants were about 0.5 m in height. In the irrigated block, one half of the nitrogen solution with sulfur was supplied after planting, and the other half was supplied in four applications through a hose-tow traveling-gun irrigation system with the exception of 1980. The four applications were made at approximately weekly intervals, with the last being made at the tasseling and silking stage. In 1980, the irrigated block was treated with the same fertility management program as the nonirrigated block. Total nitrogen applied to all treatments was about 335 kg/ha.

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Table 1.
Norfolk loamy fine sand profile description

Horizon	Depth (m)	Munsell color	Texture*	Comments
1980 and 1982 site				
Ap	0-.18	2.5 YR 4/2	lfs	single grain, very friable
E	.18-.48	2.5 YR 6/4	lfs	single grain, very friable
Bt1	.48-.76	10 YR 5/6	fsl	weak fine and medium subangular blocky structure, friable
Bt2	.76-1.07	10 YR 5/8	fsl	weak fine subangular blocky structure, friable, slightly sticky, slightly plastic
Bt3	1.07-1.32	10 YR 5/8	fsl	weak medium and coarse subangular blocky structure, firm, slightly sticky
1981 and 1983 site				
Ap	0-.23	2.5 YR 4/2	lfs	single grain, very friable
E	.23-.48	2.5 YR 6/4	lfs	single grain, very friable
Bt1	.48-.79	10 YR 5/8	fsl	weak coarse subangular blocky structure, friable, slightly sticky
Bt2	.79-1.02	10 YR 5/8	fsl	weak medium and coarse subangular blocky structure, friable, sticky, slightly plastic
Bt3	1.02-1.24	10 YR 5/8	scl	moderate medium and coarse subangular blocky structure, friable, sticky, slightly plastic

* lfs = loamy fine sand, fsl = fine sandy loam, scl = sandy clay loam.

Table 2.
Soil water contents at various soil water pressures for Norfolk loamy fine sand

Soil water pressure (kPa)	Horizon, 1980 and 1982 site			Horizon, 1981 and 1983 site		
	Ap	E	Bt1	Ap***	E	Bt1
	-------------------% Volume-------------------					
0*	37.0	38.0	41.0	53.2	37.0	38.0
-10	17.8	16.3	15.0	13.3	15.5	20.4
-20	15.2	13.9	13.4	11.3	13.5	18.7
-30	14.0	13.1	12.7	10.3	12.5	18.0
-40	13.2	12.4	12.2	9.8	11.8	17.4
-50	12.5	11.8	11.9	9.3	11.3	16.8
-60	11.9	11.5	11.7	9.0	10.8	16.7
-70	11.2	11.0	11.4	8.5	10.5	16.5
-80	10.7	10.7	11.0	8.3	9.8	16.1
-90	10.2	10.4	10.8	8.1	9.6	16.1
-100	9.8	9.7	10.6	7.8	9.4	15.7
-300**	5.8	4.9	8.7	4.5	6.0	12.6
-500**	3.8	3.6	7.2	3.3	3.7	10.9
-1500**	3.7	3.5	7.1	2.6	2.2	9.3
Bulk density (Mg/m^3)	1.67	1.64	1.57	1.24	1.67	1.63

* Calculated value.
** Disturbed samples.
*** All samples for this layer were disturbed samples.

During the 1981 growing season, calcium, manganese, and magnesium were applied through the irrigation system to the irrigated block because tissue tests indicated a deficiency of these elements. They were not applied to the nonirrigated block, because corn plants were too tall to allow application with ground equipment.

The water balance simulation model used to schedule irrigation was described by Ritchie (1972, 1973, 1974). Information needed for the water balance simulation model included plant, soil, and climatic data. Plant data needed included leaf area index and plant population. The total amount of plant available water (PAW) within the soil water control zone (top 0.46 m of the soil profile) and soil albedo were the soil data needed. Climatic data needed for the model included daily maximum and minimum temperatures, daily precipitation and irrigation, and daily total incoming solar radiation. The daily maximum and minimum temperatures and daily total incoming solar radiation were collected at a weather station 7.7 km southeast of the field site (Shaffer et al. 1981). These data

were reported for the 24-h period beginning at midnight. Daily precipitation amounts were recorded at 0730 each day from a sight rain gauge placed at the field site.

Leaf area index was calculated on a daily basis by the method described by Dale et al. (1980). By this method, the seasonal leaf area index curve was divided into three phenological periods based upon the summation of a temperature function from the day of planting to harvest. The maximum PAW in the soil water control zone was determined to be 84 mm from the data in table 2. The value was adjusted to 72 mm during the first growing season and used throughout the remainder of the study. The adjusted value was based on measured soil water content (WC) values determined when the soil profile was full of water. A constant value of 0.35 for the soil albedo was used during all growing seasons. The plant population was 90% of the planting rate for the highest plant population treatment.

The water balance simulation model calculated the daily evapotranspiration (ET) by adding the soil surface and plant surface components. Evaporation from the soil surface was calculated in two stages: (1) the constant rate stage in which soil surface evaporation was limited only by the supply of energy to the surface and (2) the falling rate stage in which water movement to the evaporating sites near the surface was controlled by hydraulic properties of the soil. Transpiration from plant surfaces was predicted by using an empirical relationship of plant surface evaporation and potential evaporation as influenced by leaf area index.

Soil WC was determined for samples taken at depths of 0 to 0.08, 0.08 to 0.15, 0.15 to 0.30, 0.30 to 0.46, and 0.46 to 0.61 m. These determinations were used to compute the measured PAW in the soil water control zone so that a comparison could be made with the PAW values calculated by the water balance simulation model.

RESULTS AND DISCUSSION

Rainfall, irrigation, soil WC (measured and calculated), and irrigation criterion are illustrated for the major part of each growing season in figures 1 and 2. The PAW values (irrigated and nonirrigated) are taken from the water balance simulation model. Measured PAW values are included in the figures to indicate accuracy of the calculated values. Each measured PAW value is based on four samples for each point during the 1980 growing season and two soil WC samples for each point during the 1981, 1982, and 1983 growing seasons.

The irrigation criterion (IC) is the level of PAW (volume percent) above which it was desired to keep the PAW during the growing season. The PAW was not allowed to drop below 20% between planting and 49 days after planting (DAP) and was maintained above 60% through the next 63 days, after which it was allowed to drop to 20%. This was based on the soil water control zone, which was constant at 0.46 m from planting to harvest.

Precipitation, irrigation, and ET totals during the 120-day corn growing season for this 4-year study are given in table 3. Average yield data for the irrigated and nonirrigated treatment are reported in table 4.

For the 1980 growing season, several late-season irrigations were applied late (fig. 1). According to the IC, the first irrigation should have been applied 52 DAP instead of 56 DAP. The calculated PAW fell below the IC for short periods of time on five other occasions during the growing season. For the nonirrigated corn in 1980, the calculated PAW dropped

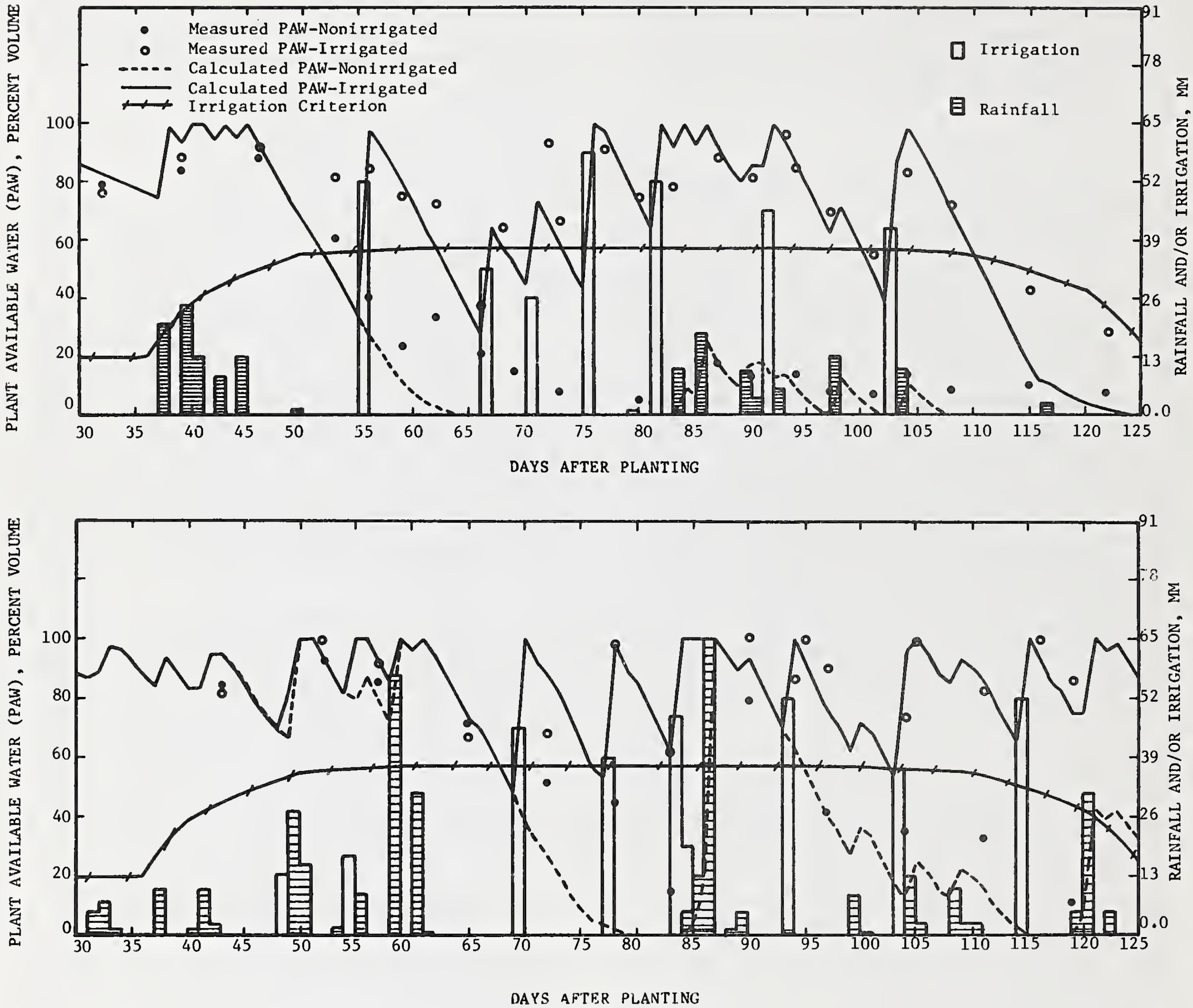

Figure 1.
Daily root-zone plant available water (PAW), irrigation, and rainfall data for irrigated and nonirrigated treatments of corn at Carrsville, VA, in 1980 (top) and 1981 (bottom).

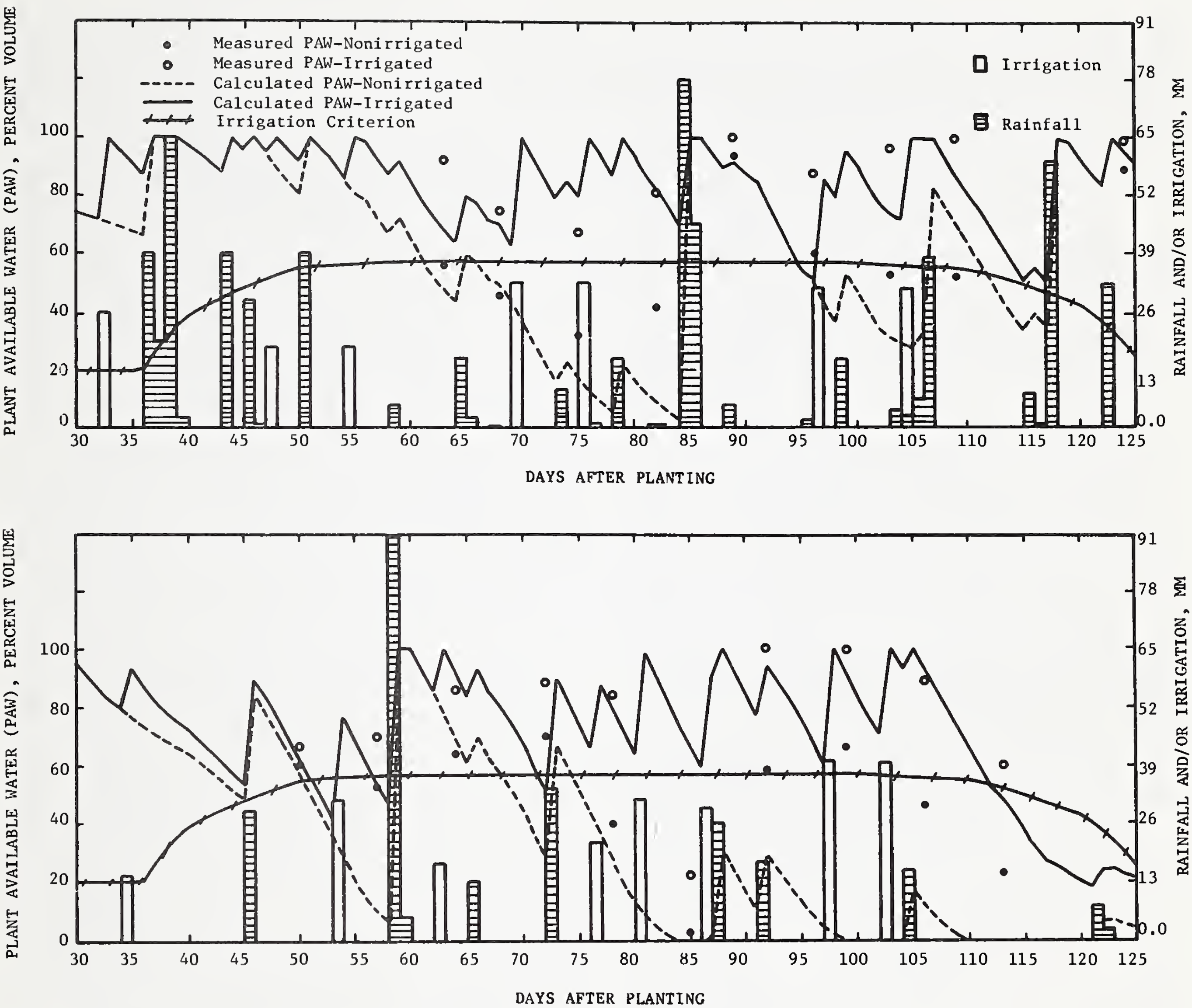

Figure 2.
Daily root-zone plant available water (PAW), irrigation, and rainfall data for irrigated and nonirrigated treatments of corn at Carrsville, VA, in 1982 (top) and 1983 (bottom).

Table 3.
Precipitation, irrigation, and evapotranspiration (ET) totals during the 120-day corn growing season for 4 years (1980-1983), Carrsville, VA

	Year							
	1980		1981		1982		1983	
	NI*	I	NI	I	NI	I	NI	I
	mm							
Precipitation	213	213	354	354	563	563	358	358
Irrigation	___	301	___	316	___	221	___	219
Total	213	514	354	670	563	784	358	577
ET Total	240	442	377	446	354	369	343	462

* NI = nonirrigated; I = irrigated.

Table 4.
Effect of irrigation on corn yields for 4 years, Carrsville, VA

Year	Corn yield Nonirrigated	Irrigated	Increase
	Mg/ha		%
1980	2.01a*	10.50b	422
1981	6.41a	12.51b	95
1982	9.18a	10.56b	15
1983	7.95a	11.40b	43
Average	6.39	11.24	76

* Values within a year followed by the same letter are not significantly different at the 1% level as determined by Duncan's multiple range test.
To convert Mg/ha to bu/A, mutiply by 16.

below the IC 52 DAP and remained below the IC for the remainder of the growing season. The calculated PAW reached this low level well before tasseling and silking, which occurred between 70 and 76 DAP. An ET deficit occurred for any given day when the calculated actual ET was less than the calculated potential ET. However, according to the calculated ET data for the irrigated plots, there was no ET deficit until 114 DAP, approximately 6 days from corn maturity. ET data for 1980 (table 3) indicate that there was 202 mm less water available for ET for the nonirrigated plots than for the irrigated plots. Yield data for 1980 (table 4) reflect the severe deficit of water in the nonirrigated plots when compared with the irrigated plots. Grain yields for the irrigated plots were 422% higher than for the nonirrigated plots.

For the 1981 growing season, all irrigations were applied within a day of the time when the calculated PAW reached the IC (fig. 1). For the nonirrigated corn, the calculated PAW dropped below the IC 68 DAP and remained there for 18 days. The crop again experienced a low calculated PAW 95 DAP and continued to remain under stress for the remainder of the growing season. According to the calculated ET data, at no time during the 120-day growing season did the irrigated corn experience an ET deficit. There was 69 mm less water available for ET for the nonirrigated plots in 1981 than for the irrigated plots (table 3). Part of this deficit occurred during the most critical part of the growing season (tasseling, silking, and pollination), approximately 74 to 84 DAP. Data for 1981 show irrigation increased yields 95% (table 4).

For the 1982 growing season, all irrigations were applied when needed according to the IC (fig. 2). The first three irrigations were required to apply a nitrogen solution. For the nonirrigated corn, the calculated PAW dropped below the IC 61 DAP for 4 days. The calculated PAW dropped below the IC three other times during the growing season, remaining below the IC for a total of 38 days. According to the calculated ET data, at no time during the 120-day growing season did the irrigated corn experience an ET deficit. There was only 15 mm less water available for ET for the nonirrigated plots in 1982 than for the irrigated plots (table 3). Data for 1982 show irrigation increased yields 15% (table 4).

For the 1983 growing season, the irrigation at 53 DAP was applied 3 days late (fig. 2). Except for two other times (1 day late each time), irrigation water was applied so that the calculated PAW remained above the IC until 112 DAP. For the nonirrigated corn, the calculated PAW dropped below the IC 52 DAP and remained there for 7 days. Except for 2 days, the calculated PAW remained below the IC from 68 DAP until the end of the growing season. According to calculated ET data, irrigated corn did not experience an ET deficit at any time during the 120-day growing season. There was 119 mm less water available for ET for nonirrigated plots in 1983 than for irrigated plots (table 3). Data for 1983 (table 4) show irrigation increased yields 43%.

With minor exceptions, the calculated PAW compared well with measured PAW for both the irrigated and nonirrigated plots during the 1980 growing season. Because of very dry soil conditions in 1980, comparisons between calculated and measured PAW values were made over a wide range of soil WC conditions. Agreement between calculated and measured PAW values was not good for the 1981 through 1983 growing seasons. One possible reason for this was that more PAW sample points were used for the measured PAW values in 1980 than in 1981 through 1983.

CONCLUSIONS

Results of this study show that (1) the Ritchie water balance simulation model works well for scheduling irrigation for corn on a Norfolk loamy fine sand in the Virginia Coastal Plains; (2) irrigation of corn increased corn yields at least 15% when total rainfall appeared adequate for crop production; and (3) for the 4 years of this study, the average corn yield increase was 76% (4.85 Mg/ha).

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APPENDIX

PROGRAM LISTINGS

LLIST SCHED

```
100 CLEAR 660: DEFINT I,J,K,M: DIM ID%(13),EP(5),RP(5),ET(10),S(10),DA(10,9),TM(5),TN(5)
,TW(5),SD(2),SR(2),P(5): ON ERROR GOTO 0
150 CLS: PRINT@522,CHR$(23);"INITIALIZING";
200 REM     INITIALIZE VARIABLES   ****
250 FOR M=1 TO 13: READ ID%(M): NEXT M
300 FOR M=1 TO 5: READ TM(M): NEXT M
350 FOR M=1 TO 5: READ TN(M): NEXT M
400 FOR M=1 TO 5: READ TW(M): NEXT M
450 FOR M=1 TO 5: READ RP(M): NEXT M
500 FOR M=1 TO 5: READ EP(M): NEXT M
550 DATA 0,31,59,90,120,151,181,212,243,273,304,334,365
600 DATA 60.0368,-1.30875E-1,4.84151E-3,-2.23851E-5,2.75113E-8
650 DATA 39.8255,-3.01194E-1,6.69080E-3,-2.94528E-5,3.63484E-8
700 DATA 39.8594,-3.23766E-1,6.99164E-3,-3.07752E-5,3.81824E-8
750 DATA 166.610,1.67867,3.05788E-2,-2.11033E-4,3.18994E-7
800 DATA 7.69797E-2,-5.40730E-4,2.66326E-5,-1.41448E-7,1.99525E-10
850 SD(1)=89.25: SD(2)=16.10: SR(1)=.7915: SR(2)=-.04261: DM=338.: LH!=6.73E-4: Q$=CHR$(
34)
900 CS=.0122: TS=16.5: CK=1.151: CH=1.187: WK=CK/CH
950 CLS: IF PEEK(16922)<>0 THEN YR%=PEEK(16922): GOSUB 6800: D$=LEFT$(TIME$,5): F%=55: G
OSUB 7450: TD%=MD: GOTO 1250
1000 PRINT@20,"TIME AND DATE INITIALIZATION." :REM*** NEEDED FOR MODEL I ONLY***
1050 PRINT@64,CHR$(31);"ENTER MINUTES -";: INPUT M: IF M<0 OR M>59 THEN 1050 ELSE POKE &
H4042,M
1100 PRINT@128,CHR$(31);"ENTER HOURS (24 HOURS CLOCK) -";: INPUT M: IF M<0 OR M>23 THEN
1100 ELSE POKE &H4043,M
1150 PRINT@192,CHR$(31);"ENTER CURRENT YEAR (YY) -";: INPUT M: IF M<79 OR M>99 THEN 1150
ELSE YR%=M: POKE &H4044,M: GOSUB 6800
1200 PRINT@256,CHR$(31);"ENTER TODAY'S DATE (M/D) -";: INPUT D$: F%=1: ON ERROR GOTO 695
0: GOSUB 7450: ON ERROR GOTO 0: POKE &H4045,DY%: POKE &H4046,MO: TD%=MD
1250 CLS: B9$=STRING$(19," "): BL$=STRING$(64," ")
1300 LC$="": PRINT@256,CHR$(31);"ENTER LOCATION WEATHER UPDATE TO BE DONE FOR - ";: INPU
T LC$: IF LEN(LC$)<5 OR LC$<"A" OR LC$>"Z" THEN 1300 ELSE IF LEN(LC$)>8 LC$=LEFT(LC$,8)
1350 LI$=LEFT$(LC$,4): LE$=LEFT$(LC$,5): PRINT@0,CHR$(31);"WEATHER REPORT FOR ";LC$;CHR$
(13);TIME$;: GOTO 1500
1400 PRINT@128,CHR$(31);"WOULD YOU LIKE TO GET HELP AND INFORMATION ON THIS PROGRAM?":IN
PUT"ENTER YES OR NO";D$: IF D$="NO" THENPRINT@128,CHR$(31);:GOTO1500
1450 IF D$<>"YES" THEN 1400 ELSE GOSUB 8200: PRINT@128,CHR$(31);
1500 OPEN"R",1,"STDWPOLS": FIELD 1, 255 AS Y$
1550 FOR I=0 TO 9: FIELD 1, I*25 AS DUMMY$, 4 AS YL$(I), 20 AS DUMMY$, 1 AS YY$(I): FOR
J=0 TO 4: FIELD 1,25*I+(J+1)*4 AS DUMMY$, 4 AS YC$(I,J): NEXT J,I
1600 MR=LOF(1): IF MR<5 RSET Y$=CHR$(13): FOR I=1 TO 5: PUT 1,I: NEXT I: I=0: GOTO 1750
1650 GET 1,1: FOR II=0 TO 9: IF LI$=LEFT$(YL$(II),4) THEN I=II:II=9: NEXT II: GOTO 2050
1700 NEXT II: FOR II=0 TO 9: IF YL$(II)="    " THEN I=II: II=9:NEXT II: GOTO 1750 ELSE N
EXT II
1750 PRINT@128,CHR$(31);"NO HISTORIC WEATHER INFORMATION FOR ";LC$;".";
1800 IF I>9 PRINT@192,CHR$(31);"NO MORE SPACE FOR THIS LOCATION IN HISTORY WEATHER FILE.
";CHR$(13);"*****   S E E   P R O G R A M M E R   *****": CLOSE: END
1850 PRINT@192,CHR$(31);"YOU CAN USE EDISTO HISTORIC WEATHER OR INITIALIZE FOR ";LC$;"."
;CHR$(13);"ENTER 'YES' TO INITIALIZE 'NO' FOR EDISTO - ";: INPUT D$: IF D$="YES" THEN 19
00 ELSE IF D$="NO" THEN 2300 ELSE 1850
1900 PRINT@192,CHR$(31);"ENTER POLYNOM COEFFICIENTS FOR TMAX (SEPARATED BY COMMAS):";: P
RINT@256,"  ";: FOR J=0 TO 4: PRINT USING"    !#     !";"A";J;",";: NEXT J: PRINT CHR$(0
8);
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1950 D$="TMAXTMINTDEWPANERAD ": FOR J=1 TO 5: PRINT@223,MID$(D$,(J-1)*4+1,4);: PRINT@320
,CHR$(31);: GET 1,J: INPUT P(1),P(2),P(3),P(4),P(5)
2000 FOR K=1 TO 5: M=K-1: RSET YC$(I,M)=MKS$(P(K)): NEXT K: LSET YL$(I)=LI$: LSET YY$(I)
=CHR$(13): PUT 1,J: NEXT J
2050 GET 1,1: FOR J=0 TO 4: TM(J+1)=CVS(YC$(I,J)): NEXT J
2100 GET 1,2: FOR J=0 TO 4: TN(J+1)=CVS(YC$(I,J)): NEXT J
2150 GET 1,3: FOR J=0 TO 4: TW(J+1)=CVS(YC$(I,J)): NEXT J
2200 GET 1,4: FOR J=0 TO 4: EP(J+1)=CVS(YC$(I,J)): NEXT J
2250 GET 1,5: FOR J=0 TO 4: RP(J+1)=CVS(YC$(I,J)): NEXT J
2300 CLOSE: PRINT@128,CHR$(31): OPEN "R",1,LE$+"/ETP": FIELD 1,255 AS S$: LSET S$=BL$+BL
$+BL$+RIGHT$(BL$,62)+CHR$(13): FOR M=0 TO 6: FOR MM=0 TO 8: FIELD 1, ((M*9)+MM)*4 AS DUM
MY$, 4 AS T$(M,MM): NEXT MM: NEXT M :FIELD 1,253 AS DUMMY$, 2 AS AW$
2350 MR=LOF(1) : IF MR=0 MC=-1: ME=0: MR=1: MW=1: GOTO 2500: ELSE GET 1,MR
2400 FOR MT=0 TO 6: IF T$(MT,0)="    " THEN M=MT: MT=6: NEXT MT: GOTO 2450 ELSE NEXT MT
2450 MU=VAL(T$(M-1,0)): MC=M-1: ME=(MR-1)*7+MC+1 :MG%=CVI(AW$)
2500 IF MW=1 THEN 2650 ELSE IF MU>=365 THEN MG%=MG%+1 :MU=0
2550 IF MU>=TD%-1 AND MG%>=YR% IF MU=TD%-1 PRINT@320,LC$;" WEATHER FILE ALREADY UPDATED
TODAY.": CLOSE: END: ELSE PRINT@320,"WRONG CURRENT DATE. FILE UPDATED MORE THAN FOR TODA
Y.";CHR$(13);"CHECK TADAY'S DATE ON TOP AND IF WRONG RESET COMPUTER.": CLOSE: E
ND
2575 PR%=1: GOTO 2750
2600 PRINT@128,CHR$(31);"WOULD YOU LIKE TO HAVE A HARD COPY OF THE DATA AND ETP?";CHR$(1
3);: INPUT "ENTER YES OR NO";D$: IF D$="NO" THEN 2750 ELSE IF D$<>"YES" THEN 2600 ELSE P
R%=1: GOTO 2750
2650 ON ERROR GOTO 6950: PRINT@256,BL$;: NT%=1: PRINT@256," ENTER STARTING DATE FOR WEAT
HER FILES (M/D) -";: INPUT D$: F%=2:        'SIGNAL NEED FOR NEW TAPES.   ****
2675 PRINT@320,"ENTER YEAR OF STATING WEATHER FILE (YY)  -";: INPUT M: IF M<79 OR M>99 A
ND M>YR% THEN 2675 ELSE YW%=M :GOSUB 6800 :MG%=YW%
2700 GOSUB 7450: MB=MD: IF MD>TD%-1 AND MG%>=YR% PRINT@384,"STARTING DAY LATER THAN YEST
ERDAY - ILLEGAL. YOU HAVE TO RETRY.";: GOTO 2650 ELSE ON ERROR GOTO 0: MD=MD-1: PRINT@25
6,BL$;: GOTO 2575
2750 PRINT@128,CHR$(31);"    ENTER BLANKS WHERE DATA NOT AVAILABLE, # TO END UPDATING.";
: PRINT@196,"ANYTIME ENTER * TO RETYPE VALUE OR & TO END LINE INPUT";
2800 PRINT@257,"DATE  TMAX TMIN RAIN IRRG WIND RAD  PEVP ETP";: IF MW=0 MD=MU
2850 MN=46: FOR M=15616 TO 16320 STEP 64: POKE M,149: IF M=16320 MN=41
2900 FOR MM=M+6 TO M+MN STEP 5: POKE MM,149: NEXT MM: NEXT M
2950 ML=0: MP=960: MS=16320: MJ=MD
3000 ML=ML+1: MK=7: MJ=MJ+1:  IF MJ>TD%-1 AND MG%=>YR%  THEN 4900 ELSE IF ML>10 THEN 485
0 ELSE GOSUB 7750: PRINT@961,DD$;
3050 FOR M=MK TO 37 STEP 5
3100 PRINT@MP+M,CHR$(14);: M1=0: M2=0: M4=0: MN=0
3150 FOR MM=M TO M+3: MN=MN+1: MZ=MP+MM
3200 IF M1>1 M1=1 ELSE IF M2>1 M2=1
3250 D$=INKEY$
3300 D$=INKEY$: IF D$="" THEN 3300
3350 IF D$="#" THEN 4600 ELSE IF D$="&" THEN PRINT@MZ,CHR$(15);" ";: GOTO 3800
3400 IF D$<>"*" THEN 3450 ELSE IF MM=7 THEN 4750 ELSE IF MN=1 PRINT@MP+M,CHR$(15);: MK=M
-5: GOTO 3050: ELSE PRINT@MZ,CHR$(15);: GOTO 3100
3450 IF (D$>"/" AND D$<":") OR D$="." OR D$="+" OR D$=" " THEN 3500 ELSE 3250
3500 IF (M1=1 OR M4=1) AND D$="+" THEN 3250
3550 IF D$="." M1=M1+1 ELSE IF D$="+" M2=M2+1
3600 IF M1>1 OR M2>1 THEN 3200
3650 IF D$<>" " M4=1
3700 IF MN=4 PRINT@MZ,CHR$(15);
3750 PRINT@MZ,D$;: NEXT MM: NEXT M
3800 FOR M=6 TO 36 STEP 5: POKE MS+M,149: NEXT M
3850 MN=1: PRINT@1004,B9$;: PRINT@1004,"CHECKING ERRORS";
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3900 FOR M=7 TO 37 STEP 5: MN=MN+1: D$=""
3950 FOR MM=0 TO 3: MW=MS+MM+M:MX=PEEK(MW): IF MX<>32 THEN D$=D$+CHR$(MX)
4000 NEXT MM
4050 IF LEN(D$)<>0 THEN DA(ML,MN)=VAL(D$): D$=D$+"    ": FOR MM=1 TO 4: POKE MS+MM+M-1,A
SC(MID$(D$,MM,1)): NEXT MM: ELSE DA(ML,MN)=1.E10
4100 NEXT M: MI=0: DA(ML,1)=MJ
4150 IF DA(ML,2)<>1.E10 AND DA(ML,3)<>1.E10 AND DA(ML,2)<DA(ML,3) MN=2: GOSUB 8100: MN=3
: GOSUB 8100
4200 IF DA(ML,2)<>1.E10 AND (DA(ML,2)>120 OR DA(ML,2)<40) MN=2: GOSUB 8100
4250 IF DA(ML,3)<>1.E10 AND (DA(ML,3)>120 OR DA(ML,3)<20) MN=3: GOSUB 8100
4275 IF DA(ML,4)<>1.E10 AND DA(ML,4)>6 MN=4: GOSUB 8100
4300 REM--IF (DA(ML,4)<>1.E10 AND DA(ML,4)>120) OR (DA(ML,2)<>1.E10 AND DA(ML,4)<>1.E10
AND DA(ML,4)>DA(ML,2)) MN=4: GOSUB8100
4350 IF DA(ML,5)<>1.E10 AND DA(ML,5)>=6 MN=5: GOSUB 8100
4400 IF DA(ML,6)<>1.E10 AND DA(ML,6)>1000 MN=6: GOSUB 8100
4450 IF DA(ML,7)<>1.E10 AND DA(ML,7)>800 MN=7: GOSUB 8100
4500 IF DA(ML,8)<>1.E10 AND DA(ML,8)>2 MN=8: GOSUB 8100
4550 IF MI<>0 PRINT@1004,"ERROR - RETYPE LINE";: GOTO 3050: ELSE PRINT@1004,B9$;: GOTO 4
700
4600 PRINT@MZ,CHR$(31);" ";: IF MM<>7 PRINT@1004,"LAST RECORD IGNORED";
4650 IF ML=1 THEN PRINT@896,"NO UPDATES RECIEVED";: END: ELSE 4900
4700 FOR M=1 TO 5: POKE 15680+(ML-1)*64+M,PEEK(MS+M): POKE MS+M,32: NEXT M: FOR M=2 TO 8
: FOR MM=(M-1)*5+2 TO (M-1)*5+5: POKE 15680+(ML-1)*64+MM,PEEK(MS+MM): POKE MS+MM,32: NEX
T MM: NEXT M: GOTO 3000
4750 IF ML<2 THEN 3250 ELSE ML=ML-1: MK=37: FOR M=2 TO 8: FOR MM=(M-1)*5+2 TO (M-1)*5+5:
POKE MS+MM,PEEK(15680+(ML-1)*64+MM): POKE 15680+(ML-1)*64+MM,32: NEXT MM: NEXT M: MJ=MJ-
1
4800 FOR M=1 TO 5: POKE MS+M,PEEK(15680+(ML-1)*64+M): POKE 15680+(ML-1)*64+M,32: NEXT M:
GOTO 3050
4850 PRINT@306,"YOU CAN NOT";: PRINT@370,"UPDATE MORE";: PRINT@434,"THAN 10 DAYS";: PRIN
T@498,"AT A TIME.";
4900 PRINT@562,"IF YOU STILL";: PRINT@626,"WANT TO MAKE";: PRINT@690,"CHANGES ENTER";: P
RINT@754,CHR$(34);"YES";CHR$(34);: PRINT@818,"OTHERWISE";: PRINT@882,CHR$(34);"NO";CHR$(
34);: PRINT@946,CHR$(14);
4950 M1=0: M2=0: D$=INKEY$
5000 D$=INKEY$
5050 D$=INKEY$: IF D$="" THEN 5050
5100 IF D$="Y" AND M1=0 AND M2=0 M1=1: GOTO 5400
5150 IF D$="N" AND M2=0 AND M!=0 M2=1: GOTO 5400
5200 IF D$="O" AND M2=1 M2=2: GOTO 5400
5250 IF D$="E" AND M1=1 M1=2: GOTO 5400
5300 IF D$="S" AND M1=2 M1=3: GOTO 5400
5350 GOTO 5000
5400 PRINT@945+M1+M2,D$;: IF M2=2 OR M1=3 THEN 5450 ELSE 5000
5450 PRINT@946+M1+M2,CHR$(15);: FOR M=0 TO 10: MN=15666+M*64: FOR MM=0 TO 12: POKE MN+MM
,32: NEXT MM: NEXT M
5500 IF M1=3 THEN 4750 ELSE PRINT@960,RIGHT$(BL$,63);: PRINT@562,"CALCULATING";: PRINT@6
29,"E T P";
5550 REM     ETP CALCULATIONS   ****
5600 FOR M=1 TO ML-1
5650 IF DA(M,2)=1.E10 ZZ=0: FOR MM=1 TO 5: ZZ=ZZ+TM(MM)*DA(M,1)[(MM-1): NEXT MM: PRINT@3
27+(M-1)*64,"";: PRINT USING"### ";ZZ;: DA(M,2)=INT(ZZ+.5):
5700 IF DA(M,3)=1.E10 ZZ=0: FOR MM=1 TO 5: ZZ=ZZ+TN(MM)*DA(M,1)[(MM-1): NEXT MM: PRINT@3
32+(M-1)*64,"";: PRINT USING"### ";ZZ;: DA(M,3)=INT(ZZ+.5)
5750 REM **** IF DA(M,4)=1.E10 ZZ=0: FOR MM=1 TO 5: ZZ=ZZ+TW(MM)*DA(M,1)[(MM-1): NEXT MM
: PRINT@337+(M-1)*64,"";: PRINT USING"### ";ZZ;: DA(M,4)=INT(ZZ+.5)
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5800 REM ****IF DA(M,4)=1.E10 DA(M,4)=DA(M,3): PRINT@337+(M-1)*64,"";: PRINT USING"### "
;DA(M,4);
5850 IF DA(M,6)<>1.E10 DA(M,6)=INT(DA(M,6)+.5): PRINT@347+(M-1)*64,"";: PRINT USING"###
";DA(M,6);
5900 IF DA(M,7)=1.E10 ZZ=0: FOR MM=1 TO 5: ZZ=ZZ+RP(MM)*DA(M,1)[(MM-1): NEXT MM: PRINT@3
52+(M-1)*64,"";: PRINT USING"### ";ZZ;: DA(M,7)=INT(ZZ+.5)
5950 IF DA(M,8)=1.E10 ZZ=0: FOR MM=1 TO 5: ZZ=ZZ+EP(MM)*DA(M,1)[(MM-1): NEXT MM: PRINT@3
57+(M-1)*64,"";: PRINT USING".###";ZZ;: DA(M,8)=INT(ZZ*1000.+.5)/1000.
6000 TK=(DA(M,2)+DA(M,3))*.5: ZZ=CS*DA(M,7)*(TK-TS)*LH!: PRINT@362+(M-1)*64,"";: PRINT U
SING".###";ZZ;: DA(M,9)=INT(ZZ*1000.+.5)/1000.
6050 NEXT M
6100 IF ML>10 GOTO 6150 ELSE GOSUB 8800
6150 FOR M=1 TO ML-1: ET(11-M)=DA(ML-M,9): NEXT M
6200 IF ME+ML>10 ZZ=0.: FOR M=1 TO 10: ZZ=ZZ+ET(M): NEXT M: PRINT@30,"LAST 10 DAYS ETP S
UM =";:PRINT USING"##.##!";ZZ;CHR$(34);
6250 IF ME+ML>7 ZZ=0.: FOR M=4 TO 10: ZZ=ZZ+ET(M): NEXT M: ZZ=ZZ*.85: PRINT@94,"LAST 7 D
AYS LAWN ETP USE =";: PRINT USING"##.##!";ZZ;CHR$(34);
6300 IF PR%=1 GOSUB 8550
6350 PRINT@960,"WHEN READY HIT ANY KEY.";: GOSUB 7300: PRINT@30,LEFT$(BL$,33);: PRINT@94
,LEFT$(BL$,33);
6400 FOR M=2 TO 14: PRINT@M*64,BL$;: NEXT M: PRINT@960,LEFT$(BL$,63);
6450 MK=0: MN=0: IF NT%<>1 GET 1,MR
6500 FOR M=MC+1 TO MC+ML-1: MN=MN+1: IF M=7 OR M=14 MK=MK+7: PUT 1,MR: MR=MR+1: LSET S$=
BL$+BL$+BL$+LEFT$(BL$,62)+CHR$(13) :FIELD 1, 253 AS DUMMY$, 2 AS AW$
6550 M1=M-MK: FOR MM=0 TO 8 :  IF DA(MN,MM+1)=1.E10 LSET T$(M1,MM)="  -1" ELSE LSET T$(M
1,MM)=RIGHT$("    "+STR$(DA(MN,MM+1)),4)
6600 NEXT MM: NEXT M: LSET AW$=MKI$(MG%) :PUT 1,MR: CLOSE 1
6650 MJ=MJ-1: GOSUB 7750: PRINT@192, CHR$(13);"REMEMBER THAT THE FILES ARE NOW UPDATED T
O ";DD$;"/";RIGHT$(STR$(YR%),2);"."
6700 IF PR%=1 LPRINT CHR$(13);CHR$(13);CHR$(13);TAB(16);"CLIMATE FILE IS NOW UPDATAED TO
";DD$;"/";RIGHT$(STR$(YR%),2);".";CHR$(13);CHR$(13)
6750 PRINT CHR$(13);CHR$(13);"PROGRAM ENDED NORMALY.": PRINT"RUN"CHR$(34)"SCHED"CHR$(34)
: RUN"SCHED/SOY"
6800 REM     LEAP YEAR DATES ADJUSTMENTS   ****
6850 IF YR%-INT(YR%/4)*4<>0 RETURN
6900 FOR M=3 TO 13: ID%(M)=ID%(M)+1: NEXT M: RETURN
6950 REM     ERROR ROUTINE   ****
7000 MK=ERR/2+1
7050 IF MK=56 THEN RESUME NEXT
7100 IF MK=1 THEN RESUME 1200
7150 IF MK>2 ON ERROR GOTO 0: RESUME
7200 PRINT@256,"REPEAT";: IF MK=1 PRINT@285,"     ";: PRINT@283,"";: ELSE PRINT@303,"
";: PRINT@301,"";
7250 INPUT D$: IF MK=2 RESUME 2700 ELSE RESUME
7300 REM     TAPE MOUNT DELAY ROUTINE   ****
7350 D$=INKEY$
7400 D$=INKEY$: IF D$="" THEN 7400 ELSE RETURN
7450 REM     DATE CHECKING ROUTINE   ****
7500 IF LEN(D$)<3 OR LEN(D$)>5 ERROR(F%)
7550 FOR MT=1 TO LEN(D$): IF MID$(D$,MT,1)="/" THEN M=MT: MT=LEN(D$): NEXT MT: GOTO 7600
ELSE NEXT MT: ERROR(F%)
7600 IF M=1 OR M=5 ERROR(F%) ELSE FOR MN=1 TO LEN(D$): MV=ASC(MID$(D$,MN,1)): IF MN<>M A
ND (MV<48 OR MV>57) ERROR(F%) ELSE NEXT MN
7650 MO=VAL(LEFT$(D$,M-1)): DY%=VAL(RIGHT$(D$,LEN(D$)-M)): IF MO<1 OR MO>12 ERROR(F%)
7700 IF DY%<1 OR DY%>ID%(MO+1)-ID%(MO) ERROR(F%) ELSE MD=ID%(MO)+DY%: RETURN
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7750 REM   DATE PREPARATION FOR PRINT   ****
7800 FOR MT=1 TO 12: IF MJ>ID%(MT+1) NEXT MT ELSE M=MT: MT=12: NEXT MT
7850 MN=MJ-ID%(M): D$=STR$(M): GOSUB 7950: DD$=D$+"/"
7900 D$=STR$(MN): GOSUB 7950: DD$=DD$+D$
7950 REM     DATE ADJUSTMENT   ****
8000 IF LEN(D$)=3 THEN D$=RIGHT$(D$,2) ELSE D$="0"+RIGHT$(D$,1)
8050 RETURN
8100 REM     INPUT ERROR SIGNAL   ****
8150 MI=1: POKE 16321+(MN-1)*5,63: RETURN
8200 REM          HELP PRINTOUT     **********
8250 PRINT@128,CHR$(31);"FOLLOWING IS A LIST OF INFORMATION AVAILABLE.";CHR$(13);"ENTER
NUMBER TO LEFT OF DESCRIPTION OR 0 END THE HELP -";CHR$(13)
8300 PRINT"1. GENERAL INFORMATION ABOUT PROGRAM.";CHR$(13);"2. DATA INPUT FORMAT.";CHR$(
13);"3. RANGES FOR INPUT DATA.";CHR$(13);"4. CALCULATION OF MISSING VALUES.";CHR$(13);
8350 PRINT"5. EVAPOTRANSPIRATION CALCULATIONS.";CHR$(13);"6. OTHER.";
8400 M=99: PRINT@246,CHR$(30);: INPUT M: IF M=0 THEN PRINT@128,CHR$(31);: RETURN: ELSE I
F M>6 THEN 8400
8450 ON M GOSUB 9100,9450,10450,10700,10950,11000
8500 GOTO 8250
8550 REM          HARD COPY ROUTINE     **********
8600 LPRINT CHR$(12);CHR$(13);CHR$(13)
8650 FOR M=15360 TO 15424 STEP 64: D$="": FOR MM=M TO M+63: D$=D$+CHR$(PEEK(MM)): NEXT M
M: LPRINT TAB(5);D$: NEXT M: LPRINT
8700 FOR M=15616 TO 15616+(ML-1)*64 STEP 64: D$="": FOR MM=M TO M+46: MN=PEEK(MM): IF MN
=149 MN=124
8750 D$=D$+CHR$(MN): NEXT MM: LPRINT TAB(16);D$: NEXT M: LPRINT CHR$(13);CHR$(13): RETUR
N
8800 REM          ROUTINE FOR GETING HISTORY ET RECORDS    **********
8850 IF NT%=1 RETURN ELSE MN=MC: MM=11-ML
8900 M1=0: M2=MR: MI=0: FOR M=MN TO MN-MM+1 STEP -1: M1=M1+1: MK=M+MI: IF MK<0 MI=MI+7:
MK=M+MI: M2=M2-1: IF M2=0 RETURN ELSE GET 1,M2
8950 ET(12-ML-M1)=VAL(T$(MK,8)): NEXT M: RETURN
9000 END
9050 PRINT@960,"WHEN READY TO CONTINUE HIT ANY KEY.";: GOSUB 7300:RETURN
9100 PRINT@128,CHR$(31);"     THIS PROGRAM IS USED IN ORDER TO MAINTAIN A WEATHER FILE";
CHR$(13);"THAT MAY BE ACCESSED BY DIFFERENT PROGRAMS THAT NEED DAILY";CHR$(13);"WEATHER
INFORMATION."
9150 PRINT"     THE PROGRAM REQUESTS BASIC WEATHER DATA AS INPUT AND";CHR$(13);"UPDATES
THE WEATHER FILE WITH THE SUPPLIED DATA (OR CALCULATED";CHR$(13);"IF DATA IS MISSING) AL
ONG WITH THE PROPER CALCULATED POTENTIAL"
9200 PRINT"EVAPOTRANSPIRATION FOR THE DAY ON A DAYLY BASIS."
9250 PRINT"     WHENEVER THE WEATHER FILE CONTAINS MORE THAN 9 DAYS, THE";CHR$(13);"CUMM
ULATIVE EVAPOTRANSPIRATION FOR THE LAST 10 DAYS IS PRINTED."
9300 PRINT"     WHENEVER THE WEATHER FILE CONTAINS MORE THAN 6 DAYS, THE";CHR$(13);"CUMM
ULATIVE LAWN EVAPOTRANSPIRATION OF THE LAST WEEK IS PRINTED.";
9350 PRINT"     A DIFFERENT WEATHER FILE IS MAINTAINED FOR EVERY LOCATION";CHR$(13);"THA
T NEEDS THIS INFORMATION."
9400 GOSUB 9050: RETURN
9450 PRINT@128,CHR$(31);"   WHILE ENTERING DATA YOU ARE SUBJECT TO RESTRICTED KEYBOARD";
CHR$(13);"FUNCTION IN ORDER TO MINIMIZE INPUT ERRORS."
9500 PRINT"   AN UPDATE OF AT MOST 10 DAYS CAN BE DONE AT A TIME.";CHR$(13);"(RUN PROGRA
M AGAIN IF MORE THAN 10 DAYS HAVE TO BE UPDATED)."
9550 PRINT"   FIRST UPDATES FOR ALL NEEDED DAYS HAVE TO BE ENTERED. ALL";CHR$(13);"INPUT
DATA WILL BE SHOWN IN A TABLE. AFTER ALL DATA IS IN";CHR$(13);"THE TABLE AND NO CORRECTI
ONS ARE REQUESTED CALCULATIONS WILL";CHR$(13);"BE DONE."
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9600 PRINT"   ALL CALCULATED VALUES FOR MISSING DATA, POTENTIAL";CHR$(13);"EVAPOTRANSPIR
ATION AND CUMMULATIVE EVAPOTRANSPIRATION WILL BE";CHR$(13);"SHOWN IN THE TABLE.";
9650 PRINT@960,"WHEN READY FOR NEXT PAGE HIT ANY KEY.";: GOSUB 7300
9700 PRINT@128,CHR$(31);"   FOLLOWING IS A LIST OF VARIABLES MAINTAINED IN THE FILE:":
9750 PRINT"     1. DATE - JULIAN DATE FOR DAY.";CHR$(13);"     2. TMAX - MAXIMUM TEMPERA
TURE FOR DAY. (DEG. F.)";CHR$(13);"     3. TMIN - MINIMUM TEMPERATURE FOR DAY. (DEG. F.)
"
9800 PRINT"     4. TDEW - DEW TEMPERATURE FOR THE DAY. (DEG. F.)";CHR$(13);"     5. RAIN
- AMOUNT OF RAIN FALL IN LAST DAY. (IN.)";CHR$(13);"     6. WIND - TOTAL WIND TRAVEL FOR
DAY. (MILES/DAY)"
9850 PRINT"     7. RAD  - SOLAR RADIATION FOR DAY. (LY.)";CHR$(13);"     8. PEVP - PAN E
VAPORATION FOR DAY. (IN.)"
9900 PRINT@960,"WHEN READY FOR NEXT PAGE HIT ANY KEY.";: GOSUB 7300
9950 PRINT@128,CHR$(31);"KEYBOARD OPERATION:": PRINT"   THE ONLY FUNCTIONAL KEYS WILL BE
THE DIGITS (0-9), PLUS (+),";CHR$(13);"COLLON (.), AND THE SPACE BAR. THE LAST TWO WILL
BE OPERATIONAL";CHR$(13);"ONLY WHEN LEGAL TO USE THEM."
10000 PRINT"   THERE ARE ALSO THREE EDITING KEYS ALWAYS OPERATIONAL:";CHR$(13);" *  - F
OR RETYPING LAST ENTERED VALUE OR VALUE IN PREVIOUS";CHR$(13);"       COLUMN OR VALUE IN
PREVIOUS LINE IN TABLE."
10050 PRINT" &  -  FOR ENDING DATA INPUT IN CURRENT LINE. CAN BE USED";CHR$(13);"
INSTEAD OF THE SPACE BAR TO SKIP ALONG THE WHOLE LINE.";CHR$(13);" #  -  FOR FINISHING D
ATA INPUT WHEN DATA TABLE NOT FULL YET."
10100 PRINT"       IF USED NOT AT LINE BEGINNING THE LINE WILL BE IGNORED.";CHR$(13);"
TO SKIP OVER COLUMNS IN THE TABLE WHEN DATA NOT AVAILABLE";CHR$(13);"YOU CAN USE ONLY TH
E SPACE BAR.";
10150 PRINT@960,"WHEN READY FOR NEXT PAGE HIT ANY KEY";: GOSUB 7300
10200 PRINT@192,CHR$(31);"   AN INPUT LINE WILL BE TERMINATED AFTER RECIEVING THE &";CHR
$(13);"EDITING KEY OR WHEN ARRIVING TO THE END OF THE LINE.";CHR$(13);"   AFTER AN INPUT
LINE ENDED IT WILL BE CHECKED FOR ERRORS. IF"
10250 PRINT"ANY ERRORS WILL BE FOUND A PROMPTING MESSAGE WILL BE PRINTED";CHR$(13);"AND
THE ERRORNEOUS VALUE(S) WILL BE FLAGED BY ? IN FRONT.";CHR$(13);"   IN CASE OF ERRORS AL
L VALUES BEFORE THE ERRORNEOUS ONES HAVE"
10300 PRINT"TO BE RETYPED.";CHR$(13);"   AFTER DATA INPUT IS FINISHED YOU WILL BE ASKED
FOR LAST";CHR$(13);"MOMENT CHANGES (LAST CHANCE FOR YOU).";CHR$(13);"   AT THE BEGINNING
OF THE INPUT LINE (LOWER LINE ON SCREEN)"
10350 PRINT"A PROMPTING DATE FOR THE CURRENT LINE WILL APPEAR.";
10400 GOSUB 9050: RETURN
10450 PRINT@128,CHR$(31);"   FOLLOWING IS A LIST OF VALID RANGES FOR INPUT DATA:"
10500 PRINT"     1. DATE - SELF MAINTAINED.";CHR$(13);"     2. TMAX -   0 <= TMAX <= 120
& TMIN <= TMAX    (DEG. F.)";CHR$(13);"     3. TMIN -   0 <= TMIN <= 120 & TMIN <= TMAX
(DEG. F.)"
10550 PRINT"     4. TDEW -   0 <= TDEW <= 120 & TDEW <= TMAX    (DEG. F.)";CHR$(13);"
5. RAIN -   0 <= RAIN <= 10     (IN.)";CHR$(13);"     6. WIND -   0 <= WIND <= 1000   (M
ILES/DAY)"
10600 PRINT"     7. RAD  -   0 <= RAD  <= 800    (LY.)";CHR$(13);"     8. PEVP -   0 <=
PEVP <= 2.0    (IN.)"
10650 GOSUB 9050: RETURN
10700 PRINT@128,CHR$(31);"   WHEN VALUES ARE MISSING DEFAULT VALUES WILL BE COMPUTED";CH
R$(13);"BY THE PROGRAM."
10750 PRINT"   THE COMPUTATION IS BASED ON HISTORICAL WEATHER RECORDS. THE";CHR$(13);"VA
LUES ARE CALCULATED BY A FOURTH DEGREE POLINOMIAL THAT WAS";CHR$(13);"FITTED TO THE MEAN
MID-MONTH HISTORICAL RECORDS."
10800 PRINT"   DEFAULT VALUES WILL BE CALCULATED FOR:";CHR$(13);"     1. TMAX";CHR$(13);
"     2. TMIN";CHR$(13);"     3. TDEW (MADE EQUAL TO TMIN)"
10850 PRINT"     4. RAD";CHR$(13);"     5. PEVP"
10900 GOSUB 9050: RETURN
10950 PRINT@128,CHR$(31);"5.....";:GOSUB 9050:RETURN
11000 PRINT@128,CHR$(31);"6.....";:GOSUB 9050:RETURN
```

LLIST WEATHER

```
100 CLEAR 650: DEFINT I-M: DIM ID(13),TM(5),TN(5),RD(5),SD(14),AW(14),TP(16),TT(16)
150 CLS: PRINT@520,CHR$(23);"INITIALIZING"
200 FOR M=1 TO 13: READ ID(M): NEXT M
250 FOR M=1 TO 5: READ TM(M): NEXT M
300 FOR M=1 TO 5: READ TN(M): NEXT M
350 FOR M=1 TO 5: READ RD(M): NEXT M
375 FOR M=1 TO 15 :READ TP(M),TT(M) :NEXT M
400 DATA 0,31,59,90,120,151,181,212,243,273,304,334,365
450 DATA 60.0368,-1.30875E-1,4.84151E-3,-2.23851E-5,2.75113E-8
500 DATA 39.8255,-3.01194E-1,6.99164E-3,-2.94528E-5,3.63484E-8
550 DATA 166.610,1.67867,3.05788E-2,-2.11033E-4,3.18994E-7
575 DATA 0.0592,0.16,0.111,0.18,0.17,0.25,0.222,0.37,0.281,0.51,0.333,0.67,0.392,0.82,0.
444,0.94,0.503,1.02,0.629,1.04,0.703,0.94,0.777,0.74,0.851,0.49,0.926,0.19,1,0.1
600 CLS: IF PEEK(&H4044)<>0 THEN D$=LEFT$(TIME$,5): M=PEEK(16922): ELSE GOTO 650
620 GOSUB 7675: F%=55: GOSUB 6650: TD%=MD: GOTO 1000
650 PRINT@20,"TIME AND DATE INITIALIZATION"
700 PRINT@64,CHR$(31);"ENTER MINUTES -";: INPUT M: IF M<0 OR M>59 THEN 700 ELSE POKE &H4
042,M
750 PRINT@128,CHR$(31);"ENTER HOURS (24 HOURS CLOCK) -";: INPUT M: IF M<0 OR M>23 THEN 7
50 ELSE POKE &H4043,M
800 PRINT@192,CHR$(31);"ENTER CURRENT YEAR (YY) -";: INPUT M: IF M<79 OR M>99 THEN 800 E
LSE POKE &H4044,M: GOSUB 7675: M=YR%
900 PRINT@256,CHR$(31);"ENTER TODAY'S DATE (M/D) -";: F%=1: INPUT D$: GOSUB 6650: POKE &
H4045,DY%: POKE &H4046,MO: TD%=MD
1000 CLS: LC$="": PRINT@128,CHR$(31);"ENTER LOCATION SCHEDULING TO BE DONE FOR -";: INPU
T LC$: IF LEN(LC$)<5 OR LC$<"A" OR LC$>"Z" THEN 1000 ELSE IF LEN(LC$)>8 THEN LC$=LEFT$(L
C$,8)
1050 LI$=LEFT$(LC$,4): LE$=LEFT$(LC$,5): PRINT@0,"SCHEDULING FOR ";LC$;CHR$(13);TIME$
1100 OPEN"R",1,"STDWPOLS": IF LOF(1)<>5 THEN 1200 ELSE FOR I=0 TO 9: FIELD 1, I*25 AS DU
MMY$, 4 AS YL$(I), 20 AS DUMMY$, 1 AS YY$: FOR J=0 TO 4: FIELD 1, 25*I+(J+1)*4 AS DUMMY$
, 4 AS YC$(I,J): NEXT J,I
1150 GET 1,1: FOR I=0 TO 9: IF LI$=LEFT$(YL$(I),4) THEN I=9: GOTO 1350 ELSE NEXT I
1200 CLOSE: FOR I=1 TO 20
1250 PRINT@128,CHR$(31);"NO HISTORIC WEATHER INFORMATION FOR ";LC$;".";CHR$(13);"EDISTO
HISTORIC RECORDS WILL BE ASSUMED.";
1300 FOR J=1 TO 50: NEXT J,I: GOTO 1500
1350 GET 1,1: FOR J=0 TO 4: TM(J+1)=CVS(YC$(I,J)): NEXT J
1400 GET 1,2: FOR J=0 TO 4: TN(J+1)=CVS(YC$(I,J)): NEXT J
1450 GET 1,5: FOR J=0 TO 4: RD(J+1)=CVS(YC$(I,J)): NEXT J: CLOSE
1500 OPEN "R",2,"SCHED/ALL": SR%=LOF(2): SR!=SR%
1550 FIELD 2, 255 AS FL$
1600 FIELD 2, 8 AS CL$, 2 AS YR$, 20 AS VI$, 2 AS PD$, 2 AS ED$, 12 AS VR$, 2 AS VL$, 20
AS ST$, 2 AS LY$, 128 AS DUMMY$, 4 AS RS$, 4 AS PP$, 2 AS LU$, 4 AS LD$, 2 AS WD$, 2 AS
YW$
1650 FOR M=1 TO 8: FIELD 2, 70+(M-1)*16 AS DUMMY$, 4 AS DL$(M), 4 AS FC$(M), 4 AS WP$(M)
, 4 AS WC$(M): NEXT M
1700 IF SR%=0 THEN GOTO 1800
1750 LT$=LEFT$(LC$+"     ",8): FOR M=1 TO SR%: GET 2,M: IF CL$<>LT$ THEN NEXT M ELSE SR%
=M: M=SR!: NEXT M:  GOTO 3400
1800 SR%=SR%+1
1850 PRINT@128,CHR$(31);"ENTER EXPERIMENT YEAR (YY) -";: INPUT YR%: IF YR%<79 OR YR%>99
THEN 1850
1900 PRINT@192,CHR$(31);"ENTER INVESTIGATOR'S NAME -";: INPUT IV$: IF LEN(IV$)>20 THEN I
V$=LEFT$(IV$,20)
1950 PRINT@256,CHR$(31);"ENTER PLANTING DATE (M/D) -";: INPUT D$: F%=2: GOSUB 6650: PD%=
MD
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2000 PRINT@320,CHR$(31);"ENTER 50% EMERGENCE DATE (M/D) -";: INPUT D$: F%=3: GOSUB 6650:
ED%=MD
2050 PRINT@384,CHR$(31);"ENTER VARIETY'S NAME -";: LINEINPUT V$: IF LEN(V$)>12 V$=LEFT$(
V$,12)
2100 PRINT@448,CHR$(31);"HOW MANY DAYS TO MATURITY -";: INPUT VL%: IF VL%<70 OR VL%>170
THEN 2100
2150 PRINT@512,CHR$(31);"ENTER SOIL TYPE -";: LINEINPUT S$: IF LEN(S$)>20 THEN S$=LEFT$(
S$,20)
2200 PRINT@576,CHR$(31);"ENTER NUMBER OF SOIL LAYERS -";: INPUT LY: IF LY<1 OR LY>8 THEN
2200
2250 FOR M=1 TO LY: IF M>4 THEN MM=4 ELSE MM=M
2300 PRINT@576+MM*64,CHR$(31);"LAYER";M;"MAX. DEPTH (IN), FC (%), WP (%) -";: INPUT DL(M
),FC(M),WP(M)
2350 IF DL(M)<4 OR DL(M)>90 OR FC(M)<5 OR FC(M)>50 OR WP(M)<1 OR WP(M)>FC(M) OR DL(M)<=D
L(M-1) THEN 2300 ELSE NEXT M
2400 PRINT@640+MM*64,CHR$(31);"ENTER ROW SPACING (IN.) -";: INPUT RS: IF RS<5 OR RS>50 T
HEN 2400
2450 PRINT@671+MM*64,CHR$(31);"PLANT POPULATION -";: INPUT PP: IF PP<1000 OR PP>200000 T
HEN 2450
2475 PRINT@128,CHR$(31);"ENTER YEAR WATER CONTENT SAMPELS WERE TAKEN   -";:INPUT GM%
2500 PRINT@192,CHR$(31);"ENTER DATE WATER CONTENT SAMPLES WERE TAKEN (M/D) -";: INPUT D$
: F%=4: GOSUB 6650: WD%=MD: D$="": IF MD>=TD% AND GM%>=YR% THEN 2500
2550 PRINT@192,"WATER CONTENT PROFILE (ENTER '0' FOR DEPTH IF NO MORE.)
2600 FOR I=1 TO 13: IF I>10 THEN II=I-10 ELSE II=I
2650 PRINT@192+64*II,CHR$(30);"SAMPLE NO.";I;"DEPTH (IN) -";: INPUT SD(I): IF SD(I)<0 OR
SD(I)>80 OR (SD(I)<SD(I-1) AND SD(I)<>0) THEN 2650 ELSE IF SD(I)=0 THEN SD(I)=SD(I-1): I
=13: GOTO  2740: ELSE SD(I+1)=SD(I)
2700 PRINT@224+64*II,CHR$(30);"W.C. (%) -";: INPUT AW(I): IF AW(I)<0 OR AW(I)>50 THEN 27
00 ELSE AW(I+1)=AW(I): NEXT I
2740 NEXT I
2750 IF I=14 AND SD(1)<>0 THEN LS=13 ELSE LS=I-1
2800 IF SD(1)=0 FOR I=1 TO LY: WC(I)=FC(I): NEXT I: GOTO 3350
2804 IF DL(LY)<SD(LS) THEN DL(LY)=SD(LS)
2805 J=0: IF SD(LS)<DL(LY) THEN SD(LS)=DL(LY)
2810 FOR N=1 TO LY:T1=DL(N)-DL(N-1): IF N<LY THEN T2=DL(N+1)-DL(N)
2811 J=J+1: T3=DL(N)-SD(J-1): T4=SD(J)-DL(N)
2815 IFSD(J)<DL(N)THENZ9=Z9+AW(J)*(SD(J)-SD(J-1))/T1:GOTO2811ELSEIFSD(J)>DL(N)ANDSD(J)=D
L(N+1)THENWC(N)=Z9+AW(J)*T3/T1:WC(N+1)=AW(J)*T4/T2:N=N+1:GOTO2825ELSEIF SD(J)>DL(N) AND
SD(J)<>DL(N)THENWC(N)=Z9+Z8+AW(J)*T3/T1:Z8=AW(J)*T4/T2:GOTO2825
2818 WC(N)=AW(J)*(DL(N)-SD(J-1))/T1+Z9+Z8: Z8=0
2825 Z9=0: NEXT N
3350 IF NF=1 THEN 3500
3400 IF LY=0 THEN PRINT@128,CHR$(31);"WOULD YOU LIKE TO REINITIALIZE WATER CONTENT WITH
NEW SAMPLES?"; ELSE IF NF=1 THEN 3750 ELSE 3550
3450 PRINT@192,CHR$(31);"ENTER 'YES' OR 'NO' -";: INPUT D$: IF D$="YES" THEN NF=1: LU=0:
GOSUB 3750: GOTO 2475: ELSE IF D$<>"NO" THEN 3450 ELSE D$=""
3500 IF NF=1 THEN 3600 ELSE 3750
3550 LSET CL$=LC$: LSET YR$=MKI$(YR%): LSET VI$=IV$: LSET PD$=MKI$(PD%): LSET ED$=MKI$(E
D%): LSET VR$=V$: LSET VL$=MKI$(VL%): LSET ST$=S$: LSET LY$=MKI$(LY): LSET YW$=MKI$(GM%)

3600 FOR M=1 TO LY: LSET DL$(M)=MKS$(DL(M)): LSET FC$(M)=MKS$(FC(M)): LSET WP$(M)=MKS$(W
P(M)): LSET WC$(M)=MKS$(WC(M)): NEXT M
3650 LSET WD$=MKI$(WD%): LSET RS$=MKS$(RS): LSET PP$=MKS$(PP): LSET LU$=MKI$(0): LSET YW
$=MKI$(GM%)
3700 PUT 2,SR%: IF NF=1 THEN NF=0
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3750 GET 2,SR%: VL%=CVI(VL$): LY=CVI(LY$): PD%=CVI(PD$): ED%=CVI(ED$): WD%=CVI(WD$): LU=
CVI(LU$): GM%=CVI(YW$): YR%=CVI(YR$): FOR M=1 TO LY: DL(M)=CVS(DL$(M)): FC(M)=CVS(FC$(M)
): WP(M)=CVS(WP$(M)): WC(M)=CVS(WC$(M)): NEXT M
3755 WD%=CVI(WD$): IF NF=1 THEN RETURN
3800 OPEN "R",1,LE$+"/ETP": MR=LOF(1): IF MR=0 THEN PRINT@128,CHR$(31);"NO WEATHER FILE
EXISTS.";CHR$(13);"RUN WEATHER PROGRAM FIRST.": CLOSE: END
3850 FOR M=0 TO 6: FOR N=0 TO 8: FIELD 1, ((M*9)+N)*4 AS DUMMY$, 4 AS T$(M,N): NEXT N,M:
FIELD 1, 253 AS DUMMY$, 2 AS YW$
3900 GET 1,MR: FOR M=6 TO 0 STEP -1: IF T$(M,0)="    " THEN NEXT M ELSE NW=VAL(T$(M,0))
3950 IF NW<>TD%-1 THEN PRINT@128,CHR$(31);"WEATHER FILE NOT UPDATED FOR TODAY.";CHR$(13)
;"FIRST BRING UP TO DATE WEATHER FILE AND THEN RERUN SCHEDULING.": CLOSE: END
4000 IF LU=0 THEN KH=WD% ELSE KH=LU
4050 IF LU=TD% THEN PRINT@128,CHR$(31);"SCHEDULING ALREADY DONE TODAY FOR ";LC$;CHR$(13)
;"PROGRAM TERMINATED.": CLOSE: END
4100 GET 1,1: KF=VAL(T$(0,0)): KD=VAL(YW$(0))
4110 IF KF>KH AND KD>=YR% THEN PRINT@128,CHR$(31);"WEATHER FILES DO NOT GO BACK TO THE D
ATE WATER CONTENT TAKEN";CHR$(13);"INITIAL WATER CONTENT WILL BE ASSUMED TO BE FOR FIRST
";CHR$(13);"WEATHER DAY IN FILE": ELSE 4175
4150 I1=1: I2=0: FOR I=1 TO 500: NEXT I: GOTO 4450
4175  IF KF>KH THEN KF=KF-365-1
4200 I=KH-KF-1: I1=INT(I/7)+1: IF I1<1 THEN GOTO 4400
4250 I2=I-(I1-1)*7: GET 1,I1: IX=1: GOSUB 7820: IX=0: IF RAIN>=25 THEN IR=3: GOTO 4400
4300 I=KH-KF-2: I1=INT(I/7)+1: IF I1<1 THEN GOTO 4400
4350 I2=I-(I1-1)*7: GET 1,I1: IX=1: GOSUB 7820: IX=0: IF RAIN>=25 THEN IR=2
4400 I=KH-KF: I1=INT(I/7)+1: I2=I-(I1-1)*7
4450 GET 1,I1: I0=VAL(T$(I2,0)): I2=I2-1: IF I0>TD% THEN I7=I0-365 ELSE I7=I0:
4475 GOSUB 8000
4500 FOR JJ=I7 TO TD%-1: IR=IR-1 :TG=0 :RI=0 :EW=0 :IF JJ<=0 THEN M=365+JJ ELSE M=JJ
4550 I2=I2+1: IF I2=7 THEN I2=I2-7: I1=I1+1: GET 1,I1
4600 GOSUB 6900
4650 GOSUB 7450
4700 PRINT@128,CHR$(31);"ROOT ZONE DEPTH ON ";DD$;" -";: INPUT DR: IF DR<=0 OR DR>70 THE
N 4700 ELSE IF DR+4>DL(LY) THEN DL(LY)=DR+4
4750 PRINT@162,CHR$(31);"ALLOWABLE DEPL. (%) -";: INPUT DA: IF DA<20 OR DA>90 THEN 4750
4800 GOSUB 7820
4820 IF TG=1 THEN PRINT@192,CHR$(31);"ENTER NO. OF RETETION DAYS (0,1 OR 2) FOR EXCESSED
WATER";: INPUT RW :IF RW<0 OR RW>2 THEN 4820
4821 IF TG=1 THEN GOTO 4830
4825 RW=RW-1
4830 GOSUB 7955
4850 GOSUB 7340
4900 GOSUB 6950
4950 ET=VAL(T$(I2,8)): GOSUB 7700
5000 GOSUB 7340
5050 IF T$(I2,5)="  -1" THEN RSET T$(I2,5)=" "
5100 LPRINT DD$;"  ";: FOR N=1 TO 8: LPRINT T$(I2,N);"  ";: NEXT N
5150 LPRINT USING"#.## #.## .### ##.#   ##   ##.#  ##.##    ##.##  #.##";KS!;CF;
AET;DR;DA;TW/WM*100;TW;WM-TW;EW;
5200 IF TW/WM<=1-DA/100 THEN LPRINT" IRRIG NEEDED." ELSE LPRINT" "
5250 NEXT JJ
5300 FOR J=1 TO LY: LSET WC$(J)=MKS$(WC(J)): NEXT J: LSET LU$=MKI$(M+1)
5350 LPRINT CHR$(13);CHR$(13);"FORECAST:"
5400 LPRINT CHR$(13);" DATE  TMAX  TMIN  RAD  ETP  KS    KC    AETP  RD  AWC(%) AWC
(IN)  DPL(IN)"
5450 PRINT@128,CHR$(31);"FORECAST FROM WEATHER SERVICE:    (IF NO FORECAST ENTER -1)"
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5500 FOR M=TD% TO TD%+4: GOSUB 7450: IR=IR-1
5550 PRINT@192,CHR$(31);"TMAX, TMIN, % MAX. RAD. - FOR ";DD$;" -";: INPUT TX,TI,PR
5600 IF (TX<>-1 AND (TX<0 OR TX>120)) OR ((TX<>-1 AND TI<>-1) AND (TI>TX OR TI<0)) OR (P
R<>-1 AND (PR<1 OR PR>850)) THEN 5550
5650 ZZ=0: FOR J=1 TO 5: ZZ=ZZ+RD(J)*M[(J-1): NEXT J: Z1=ZZ
5700 IF PR<>-1 THEN Z1=PR ELSE Z1=ZZ
5750 IF TX=-1 THEN ZZ=0: FOR J=1 TO 5: ZZ=ZZ+TM(J)*M[(J-1): NEXT J: TX=ZZ
5800 IF TI=-1 THEN ZZ=0: FOR J=1 TO 5: ZZ=ZZ+TN(J)*M[(J-1): NEXT J: TI=ZZ
5850 ET=0.0122*Z1*((TX+TI)/2-16.5)*6.73E-4
5900 GOSUB 6900: GOSUB 6950: GOSUB 7000: GOSUB 7700: GOSUB 7340
5950 LPRINT DD$;"  ";: LPRINT USING" ###   ###   ###  .###  #.##  #.##   .###  ##.#  ##.
#   ##.##    ##.##";TX;TI;Z1;ET;KS!;CF;AET;DR;TW/WM*100;TW;WM-TW;
6000 IF TW/WM<=1-DA/100 THEN LPRINT "   IRRIGATION NEEDED." ELSE LPRINT " "
6050 NEXT M
6100 IF TW/WM<=1-DA/100 THEN GOTO 6600 ELSE PRINT@128,CHR$(31);"CHECKING FORECAST FOR NE
XT IRRIGATION."
6150 FOR M=TD%+5 TO PD%+VL%-1
6200 ZZ=0: FOR J=1 TO 5: ZZ=ZZ+RD(J)*M[(J-1): NEXT J: Z1=ZZ
6250 ZZ=0: FOR J=1 TO 5: ZZ=ZZ+TM(J)*M[(J-1): NEXT J: TX=ZZ
6300 ZZ=0: FOR J=1 TO 5: ZZ=ZZ+TN(J)*M[(J-1): NEXT J: TI=ZZ
6350 ET=0.0122*Z1*((TX+TI)/2-16.5)*6.73E-4
6400 GOSUB 6900: GOSUB 6950: GOSUB 7700: GOSUB 7340
6450 IF TW/WM<=1-DA/100 THEN GOSUB 7450: LPRINT CHR$(13);CHR$(13);"FORECAST FOR NEXT IRR
IGATION IS ON ";DD$;".": GOTO 6600
6500 NEXT M
6550 LPRINT CHR$(13);CHR$(13);"NO IRRIGATION IN FORECAST TO THE END OF THE SEASON."
6600 GET 1,1: PUT 2,SR%: CLOSE: PRINT@128,CHR$(31);: PRINT@448,"PROGRAM ENDED NORMALY.":
PRINT"RUN"CHR$(34)"WEATHER"CHR$(34): RUN"WEATHER": END
6650 ON ERROR GOTO 8100: IF LEN(D$)<3 OR LEN(D$)>5 ERROR(F%)
6700 FOR MT=1 TO LEN(D$): IF MID$(D$,MT,1)="/" THEN M=MT: MT=LEN(D$): NEXT MT: GOTO 6750
ELSE NEXT MT: ERROR(F%)
6750 IF M=1 OR M=5 ERROR(F%) ELSE FOR MN=1 TO LEN(D$): MV=ASC(MID$(D$,MN,1)): IF MN<>M A
ND (MV<48 OR MV>57) ERROR(F%) ELSE NEXT MN
6800 MO=VAL(LEFT$(D$,M-1)): DY%=VAL(RIGHT$(D$,LEN(D$)-M)): IF MO<1 OR MO>12 ERROR(F%)
6850 IF DY%<1 OR DY%>ID(MO+1)-ID(MO) ERROR(F%) ELSE MD=ID(MO)+DY%: ON ERROR GOTO 0: RETU
RN
6900 IF M<PD% THEN TF=(M+365-PD%)/VL% ELSE TF=(M-PD%)/VL%  '** % OF GROWING SEASON
6910 TB=TF/.69: TA=M-PD%-.69*VL%: RETURN
6950 IF TF<.69 THEN CF=-1.583*TB[3+2.756*TB[2-.4276*TB+.17 ELSE  CF=2.75E-6*TA[3-4.688E-
4*TA[2+1.195E-2*TA+.915  '**CROP FACTOR FOR DATE
7000 IFTW/WM>.403158 THEN KS!=1*LOG(1+TW/WM*100)/LOG(101) ELSE KS!=2*TW/WM
7025 SF=KS!*CF
7050 IF IR<1 THEN RETURN
7100 IF IR=1 THEN SF=SF+.3*(.9-SF): GOTO 7250
7150 IF IR=2 THEN SF=SF+.5*(.9-SF): GOTO 7250
7200 IF IR=3 THEN SF=SF+.8*(.9-SF)
7250 IF SF>1 THEN SF=1.00
7300 RETURN
7340 IF DL(LY)<DR+4 THEN DL(LY)=DR+4
7350 TW=0: WM=0: ZZ=DR+4: FOR N=1 TO LY: IF ZZ>DL(N) THEN TW=TW+(WC(N)-WP(N))*(DL(N)-DL(
N-1)): WM=WM+(FC(N)-WP(N))*(DL(N)-DL(N-1)): NEXT N: ELSE TW=TW+(WC(N)-WP(N))*(ZZ-DL(N-1)
): WM=WM+(FC(N)-WP(N))*(ZZ-DL(N-1)):N=LY:NEXT N  '** WATER IN PR
7400 TW=TW/100: WM=WM/100: IF TW<0 THEN TW=.001RETURN
7410 RETURN
7450 FOR JT=1 TO 12: IF M>ID(JT+1) NEXT JT ELSE J=JT: JT=12: NEXT JT  '** DATE IN MM/DD
FORM
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7500 MN=M-ID(J): D$=STR$(J): GOSUB 7600: DD$=D$+"/"
7550 D$=STR$(MN): GOSUB 7600: DD$=DD$+D$: RETURN
7600 IF LEN(D$)=3 THEN D$=RIGHT$(D$,2) ELSE D$="0"+RIGHT$(D$,1)
7650 RETURN
7675 IF M=INT(M/4)*4 THEN FOR J=3 TO 13: ID(J)=ID(J)+1: NEXT J :ELSE  RETURN
7680 RETURN
7700 AET=SF*ET: ZZ=AET: FOR N=1 TO LY: EQ=DL(N)-DL(N-1) '** GET OUT ET FROM ROOT ZONE
7750 WC(N)=WC(N)-ZZ*100/EQ: IF WC(N)<WP(N) ZZ=(WP(N)-WC(N))*EQ/100: WC(N)=WP(N): NEXT N
ELSE N=LY: NEXT N
7800 RETURN
7820 IF T$(I2,3)="  -1" THEN RSET T$(I2,3)=" "     '** ADD RAIN
7830 IF T$(I2,4)="  -1" THEN RSET T$(I2,4)=" "
7840 RAIN=(VAL(T$(I2,3))+VAL(T$(I2,4)))*100: IF IX=1 THEN RETURN
7900 IF RAIN<10 THEN RETURN ELSE IF RAIN>=25 THEN IR=3
7950 RI=0: FOR J=1 TO LY: WC(J)=WC(J)+RAIN/(DL(J)-DL(J-1)): IF WC(J)>FC(J) THEN RAIN=(WC
(J)-FC(J))*(DL(J)-DL(J-1)): WC(J)=FC(J): NEXT J: RI=RAIN/DL(1)-DL(0): WC(1)=WC(1)+RI: TG
=1 :RETURN ELSE J=LY: NEXT J:RETURN
7955 IF RW=0 AND WC(1)>FC(1) THEN EW=(WC(1)-FC(1))*DL(1)/100 :WC(1)=FC(1)
7960 RETURN
8000 LPRINT CHR$(12);CHR$(13);CHR$(13);CHR$(13);TAB(30);"IRRIGATION SCHEDULING FOR ";LC$
;CHR$(13);TAB(37);TIME$;CHR$(13);"BACK RECORDS:" '** OUTPUT HEADING
8050 LPRINT CHR$(13);" DATE  TMAX  TMIN  RAIN  IRRG  WIND   RAD  PEVP   ETP  KS    KC
AETP   RD   AD(%)  AWC(%)  AWC(IN)";
8060 LPRINT "  DPL(IN)  EW(IN)": RETURN
8100 ON F% GOTO 8200,8250,8300,8350
8150 STOP
8200 RESUME 900
8250 RESUME 1950
8300 RESUME 2000
8350 RESUME 2500
9000 LPRINT"ABCDE":GOTO 9000
```

DICTIONARY OF TERMS

WEATHER

AW$	Year of experiment in weather file buffer, years
B9$	String of blanks, dimensionless
BL$	String of blanks, dimensionless
D$	Temporary or intermediate strings, dimensionless
DA$	Temporary or intermediate array, dimensionless
DD$	Gregorian date, day of month
DY	Day of the current date, day of month
EP	Array of historical pan evaporation coefficients, in/day to in/day^5
ET	Calculated evapotranspiration, in/day
F	Error recovery flag, dimensionless
I	Purpose counter, dimensionless
ID	Number of days in each month, days
J	General purpose counter, dimensionless
K	General purpose counter, dimensionless
LC$	Full location name, dimensionless
LE$	First five characters of the location name, dimensionless
LI$	First four characters of the location name, dimensionless
M	General purpose and day of year counter, dimensionless
M1	Decimal point flag, dimensionless
M2	Plus sign flag, dimensionless
M4	Space bar flag, dimensionless
MC	Pointer for first record in weather file, dimensionless
MD	Temporary value of day of year, days
ME	Number of days in weather file, days
MG	Year of creating weather file, year
MI	Flag for input error, dimensionless
MJ	Counter of days to be updated in weather file, days
MK	Pointer of cursor location in weather table, dimensionless
ML	Counter of maximum possible days that can be updated in one run, days
MM	General purpose counter, dimensionless
MN	Flag for turning cursor on and off, dimensionless
MO	Month of the year, month
MP	Last location of weather table on screen, dimensionless
MR	Number of records in weather file, number
MS	Memory location for temporary storage of weather table, dimensionless
MU	Last day in weather file, days
MV	General purpose variable, dimensionless
MW	Flag that this is beginning of new weather file, dimensionless
MX	General purpose variable, dimensionless
MZ	Current location of cursor, dimensionless
NT	Flag that this is the first run for the location, dimensionless
P	Array holding coefficients of historical weather polynomials, ^oF to $^oF/day^4$, ly to ly/day^4, in/day to in/day^5

PR	Flag for hard copy routine, dimensionless
RP	Array holding coefficients of historical radiation polynomial, ly to ly/day^4
S$	General purpose string character, dimensionless
T$	Holds the daily weather information in the weather file buffer, $^\circ$F, in, mile/day, ly, in/day
TD	Current day of year, day
Tk	General purpose variable, dimensionless
TM	Historical maximum temperature polynomial coefficients, $^\circ$F to $^\circ$F/day^4
TN	Historical minimum temperature polynomial coefficients, $^\circ$F to $^\circ$F/day^4
TW	Historical dew point temperature polynomial coefficient, $^\circ$F to $^\circ$F/day^4
Y$	Holds ASCII code for line feed, dimensionless
YC$	Historical weather polynomial coefficients in the weather file buffer, dimensionless
YL$	First four characters of the location name, dimensionless
YR	Current year, years
YW	Year that the weather file started, years
YY$	Holds dummy characters in the weather file, dimensionless
ZZ	Temporary variable, dimensionless

SCHED

AE	Actual evapotranspiration from soil profile, in/day
AW	Array holding the water content of soil samples, in
CF	Crop factor, percent of season, dimensionless
D	Temporary or intermediate string, dimensionless
DA	Allowable depletion, dimensionless
DD	Holds Gregorian date, day
DL	Array of layer, depths, in
DR	Rooting depth, in
DU	Dummy areas in file buffers, dimensionless
DY	Day of the month, day
EA	Cumulative water content in soil layer, in
ED	50% emergence day of year, day
EQ	Available water in soil layer, in
EW	Excess water over field capacity, in
ET	Calculated potential evapotranspiration, in/day
F	Error recovery flag, dimensionless
FC	Field capacity array for each layer, dimensionless
FL	Define the whole sites file buffer, dimensionless
GM	Starting year of the experiment, year
I	General purpose counter, dimensionless
I0	Day of year of first back record to be processed, day
I1	Record counter for weather file, record
I2	Day counter of record in weather file, day
I7	Day counter, day
ID	Number of days in the year, day

II	Counter for line number on screen, line
IR	Irrigation or rain flag, dimensionless
IV	Investigator name, dimensionless
IX	Flag of irrigation or rain check, dimensionless
J	General purpose counter, dimensionless
JJ	General purpose counter, dimensionless
KD	Year experiment started, year
KF	Day of year of first day in weather file, day
KH	Day of year of last scheduling run, day
KS	Soil coefficients, dimensionless
LC$	Full location name, dimensionless
LD$	Unused space in file buffer, dimensionless
LE$	Five first characters in location name, dimensionless
LI$	Four first characters in location name, dimensionless
LS	Soil sample counter, dimensionless
LT$	Full location name, dimensionless
LU	Last scheduling date in sites file, day
LY	Number of soil layers, dimensionless
M	General purpose counter, dimensionless
MD	Temporary value of day of year, day
MM	General purpose counter, dimensionless
MN	General purpose counter, dimensionless
MO	Month of the year, month
MR	Number of records in the weather file, record
MV	General purpose variable, dimensionless
N	Current layer number and general variable, dimensionless
NF	Water content reinitialization flag, dimensionless
NW	Day of year of last day in weather file, day
PD	Julian planting date, day
PP	Plant population, plant/acre
PR	Forecast solar radiation, ly
RA	Depth of rain or irrigation, in
RD	Array of coefficients in historical radiation polynomial, ly
RI	Excess rain and/or irrigation, in
RS	Row spacing, in
RW	Number of days to hold excess water, before dropping as either runoff or deep percolation, day
S$	Soil type, dimensionless
SD	Soil sample depth, in
SF	Soil and crop coefficient, dimensionless
SR	Number of records in site file, record
ST$	Soil type, dimensionless
T$	Array of daily weather information, ^{o}F, in, mile/day, ly, in/day
TA	Time in days of current date after full cover, day
TB	Percent of time from date of full cover, dimensionless
TD	Current date, day
TF	Percent of time from full season, dimensionless
TG	Flag for excess water, dimensionless

TM	Maximum temperature historical polynomial coefficient, $^{o}F/day$ to $^{o}F/day^{5}$
TN	Minimum temperature historical polynomial coefficient, $^{o}F/day$ to $^{o}F/day^{5}$
TP	Array holding crop coefficient, dimensionless
TT	Array holding dates for crop coefficient, day
TW	Actual amount of water available in the root zone, in
TX	Maximum temperature forecast, ^{o}F
V$	Variety name, dimensionless
VI$	Investigator name, dimensionless
VL	Time in days to crop maturity, day
VR$	Holds variety name in the site buffer, dimensionless
WC	Current water content of soil layer, in
WD	Day of year when soil samples were taken, day
WM	Maximum amount of water possible in root zone, in
WP	Wilting point of soil layers, dimensionless
YC$	Historical weather polynomial coefficients in the weather file buffer, dimensionless
YL$	First four characters of location name, dimensionless
YR	Current year, year
YW	Year water content samples were taken, year
YY$	Dummy character in weather file buffer, dimensionless
Z1	Temporary variable, dimensionless
Z8	Temporary variable, dimensionless
Z9	Temporary variable, dimensionless
ZZ	Temporary variable, dimensionless

ANNOTATIONS TO PROGRAM

WEATHER

100-200	Declaration, dimensions, and initialization
250-800	Reads in coefficients of historical weather polynomials
950-1200	Time and date initialization routine for TRS-80 Model I
1250-1450	Accepts location name and asks user about help requests
1500-1650	Opens and fills file for historical weather polynomials and finds the record of the current location
1700-1950	Notifies user if there is no information for current location or no more space and asks if historical weather polynomial coefficients for current location is acceptable
2000-2250	Read in historical weather coefficients from file
2300-2450	Opens weather file for the location, checks for data and retrieves data of last day
2500-2600	Notifies user about status of weather file and of data mismatch, if there is any. Asks user if he or she wants hard copy
2650-2700	Accepts starting date of weather file and checks for date mismatch
2750-2800	Prints header of table for weather information input
2850-3000	Routine to poke in memory location weather information check and print the date of day to be updated
3050-3750	Routine uses INKEY$ function to input weather information. Locks out all keyboard keys except numeric keys and *,#,$.
3800-4500	Routine for checking typing error in the input weather table
4550-4600	Error message to user
4700-4800	Poke table in random access memory
4850-4900	Asks user if he or she wants to make changes
4950-5450	Evaluates user response and sends program back to table to make changes or let program proceed
5500-6050	Routine that calculates potential evapotranspiration for each day and prints it in the table on the screen
6100-6300	Calculates evapotranspiration sum of last 10 days and loads evapotranspiration for last 7 days
6350-6750	When user notifies that he or she is ready, the weather information table is stored on disk, as it is printed on screen and the user is notified that weather file is updated until today and scheduling program is run automatically
6800-6900	Leap year dates adjustment subroutine
6950-7250	Error routine subroutine
7300-7400	Tape mount delay subroutine
7450-7700	Date checking routine
7750-8050	Date preparation for print routine
8100-8150	Input error signal subroutine

8200-8500	Help printout subroutine if user asks for help; this subroutine will give information on the type of help available
8550-8750	Hard copy subroutine will send input weather table to the printer
8800-8950	History evapotranspiration records retrieval subroutine
9050-11000	Help subroutine which prints directions on screen for the inexperienced user

SCHED

10-150	Initialization and dimensions
200-575	Reads in values of historical weather polynomial coeffients
600-900	Time and date initialization for Model I; Model III will do it in DOS mode
1000-1050	Location name input and prints message of scheduling
1100-1200	Opens historical weather polynomial file and finds the record of current location
1250-1300	If no record exists, prints message and tells user that Edisto data will be used
1350-1450	Read in polynomial coefficients
1500-1750	Opens site parameters file "SCHED/ALL" and looks for site parameters; if there, skips to line 3400; if not, goes to line 1800
1800-2450	Accepts site parameters in the following sequence: Experiment year, investigator´s name, planting date, 50% emergence date, variety, days to maturity, soil type, soil layers, depth, field capacity, wilting point, row spacing, and plant population
2475-2740	Routine to accept soil water content samples for up to 13 depths
2750-2804	Adjustments between soil water content samples and soil profile layers
2805-2825	Routine that calculates actual water content in each layer of soil profile according to water content samples
3350-3500	If this is not first run, asks user if he or she would like to reinitialize soil water content. If so, goes back to water content sample input routine. If not, goes to routine that retrieves site parameters
3550-3700	Puts site parameters in site parameters file in the appropriate record
3750-3755	Routine to retrieve site parameters
3800-3900	Opens current weather file for the location and finds the last updated day
3950-4110	If there is any date mismatch, user is notified and asked to take the proper measures according to type of mismatch

4150	Starts back records at first day in weather file, then skips to line 4450 to start producing back records
4175-4400	Goes up to 3 days back in weather file to check for rain or irrigation. If any occurred, sets the rain or irrigation flag to the proper value
4500-5150	Loop that processes and prints back records between the last day of previous run and yesterday. Calculates water content and depletion from the rooting depth each day and prints daily weather information and water content status
5300	Sets current water content in weather file buffer
5350-5450	Prints header for forecast input weather information routine
5500-6050	Loop that accepts forecast of daily weather information, calculates evapotranspiration and soil water content and prints daily forecast
6100-6550	Routine to check forecast of daily weather information, calculates evapotranspiration and soil water content and prints daily forecast
6600	Puts updated information in site file and notifies user that program ended
6650-6850	Date check and date conversion subroutine
6900	Percent of growing season calculation subroutine
6950-7300	Crop and soil coefficients calculation subroutine
7350-7400	Water content in soil root zone calculation subroutine
7450-7550	Conversion of day of year to Gregorian date subroutine
7600-7650	Date string adjustment subroutine
7700-7800	Subroutine to deplete actual evapotranspiration from soil root zone
7850-7960	Rain and irrigation addition to soil root zone subroutine
8000-8060	Back records heading printout subroutine
8100-8350	Jump to line number corresponding to value of the error flag

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